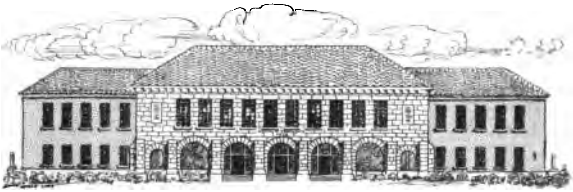
ELEMENTARY PHYSICAL SCIENCE

JOHN F. WOODHULL



ELEMENTARY

PHYSICAL SCIENCE

FOR GRAMMAR SCHOOLS

BY

JOHN F. WOODHULL, Ph.D.

PROFESSOR OF PHYSICAL SCIENCE, TEACHERS COLLEGE
COLUMBIA UNIVERSITY, NEW YORK CITY

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PREFACE

The widespread demand that Elementary Physical Science should be introduced into the grammar schools has been met by the New York City Board of Education, and a very complete syllabus was prepared in 1904 prescribing work for the seventh and eighth grammar grades.

The purpose of this Text-book of Elementary Physical Science is to carry out the intention of the Board of Education that a text-book should be given to the pupils, and lessons assigned to follow the experiments prescribed in the syllabus — a book to aid the teacher to correlate the experimental work with the experiences in the daily lives of the pupils and with the other subjects of the grade. Information is not to be denied to pupils in that field where information is most desired and most needed.

Typical experiments, approved by the Board of Superintendents, are printed at the head of the appropriate sections of this book. The intention is that the teachers shall first perform the experiments prescribed for a given topic, with such inductive work as may be necessary, and afterward assign the appropriate lesson from this Book of Information.

This book aims, first, to give the pupil accurate verbal concepts of ideas that have already entered his consciousness through his senses; second, to broaden his knowledge by calling his attention to practical applications of the principles that he has seen illustrated in the laboratory.

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ELEMENTARY PHYSICAL SCIENCE

MATTER

Experiments

Physical Change. — Molecule. Pulverize lump of common or rock salt. Dissolve in water. Test solution by taste. Dissolve a small piece of copper sulphate in water. Test solution with ammonia. Expose tuft of cotton wet with ether or carbon bisulphide. Observe whether particles are distributed throughout air of room. What do these experiments show as to divisibility and distribution of materials used?

Chemical Change. — Atom. Heat red oxide of mercury in small test tube, held horizontal. Observe collection of material on cold part of tube. Introduce glowing match. Observe result. Pour concentrated sulphuric acid into 2 oz. of saturated sugar solution. Note materials formed.

States of Matter. — Put piece of ice in test tube, and heat until some of water formed disappears. In what states did the matter exist? Place cold plate or glass or tumbler at mouth of test tube. What collects on glass? Could anything be seen passing from surface of water in test tube to plate or tumbler? In what state did matter pass from surface of water to plate? Melt a piece of paraffin in test tube. Heat a crystal of iodine in small flask closed with tuft of cotton. In what states was matter observed?

When sugar is dissolved in water, very small particles, which we call *molecules*[1] of sugar, are distributed throughout the water and exist side by side with molecules of water. If, by the sense of taste or by other means more

[1] *Molecule* simply means "little mass."

delicate, we test the smallest portion which we can take of this water, we find that sugar is present with it. The sugar and the water are mixed together as we might mingle particles of sugar and salt. We may by various means convince ourselves that these molecules are extremely small, far smaller than any microscope can detect. A drop of nitric acid, for example, mixed into a tank of water containing twenty million times its own volume, can be detected as present in every drop of the mixture.

All substances, whether soluble in water or not, are composed of molecules. The fact that the molecules of sugar find room to enter among the molecules of water indicates that there are spaces between molecules. Our future study will convince us that in all forms of matter, even the most compact solid, there are spaces between molecules larger than the molecules themselves, and that the molecules of all substances are in quivering motion at all times. Heating a substance causes this molecular motion to increase. The spaces are thus enlarged by the beating of molecules against their neighbors, and in this way heat causes the substance to expand.

Under the influence of heat the molecules may separate so as to change the state of the substance from solid to liquid, thus sugar may melt; or, if heated so as to enlarge the spaces still more, the liquid may become a gas, as when water is boiled to form steam. On cooling, these substances return to their original state. Such changes are called *physical changes.*

When, however, we heat sugar above its melting point, we do something more than separate molecules farther apart: we decompose molecules into smaller particles, called *atoms*, of substances wholly unlike sugar, and this is called a *chemical change.*

PROPERTIES OF MATTER

Experiments

Indestructibility. — Dissolve bit of copper wire in dilute nitric acid. Dip knife blade or knitting needle into solution. Was copper destroyed by being dissolved?

Inertia. — Suspend heavy weight by long string. Attach thread to weight and pull gently in horizontal direction; then pull suddenly. Arrange weight and thread as before. Set weight swinging through wide arc. Attempt to check motion gradually, then suddenly. What happens to thread in each case, and why? Place weight (*e.g.* a book) on sheet of paper resting on table top. Pull paper slowly, then suddenly. What happens in each case? Why?

Impenetrability. — Fit 8-oz. bottle with two-hole rubber stopper, slender funnel, and rubber delivery tube. Pinch delivery tube and pour water into funnel; then release delivery tube. Account for difference in results. Fill long tube, closed at one end, half full of colored water; then, holding tube inclined carefully pour in alcohol until tube is nearly full. Mark upper level of alcohol with rubber band. Close end, and mix thoroughly by inverting several times. What change in volume of contents has occurred? Why?

By heat sugar may be broken into three elements, and these three elements may be made to form new compounds; but no process has been discovered whereby we may either destroy or create one atom of these or any other elements. All chemical changes which appear to destroy substances are merely changes of form. For example, when a ton of coal is burned, about one fifth of it remains as ashes, and the other four fifths go up the chimney in the form of gas; and even in the case of a gas, four fifths of a ton is still sixteen hundred pounds. We shall learn why it goes up the chimney when we study about buoyancy of the air.

Matter may be changed in form, but we can neither create nor destroy it.

Our experiences in riding upon a street car may teach us much about inertia. We learn most about it when we are standing up holding on to a strap. When the car suddenly starts, we find that *a body at rest tends to remain at rest*, and it is necessary for us to pull hard at the strap to get ourselves in motion. When the car suddenly stops, we find that *a body in motion tends to continue moving*, and it is necessary for us to pull hard again at the strap to check our motion. When the car suddenly turns a street corner, we find that a body in motion tends to continue moving *in a straight line*, and it is necessary for us to pull hard again at the strap to change the direction of our motion. This, then, is the law of inertia. *A body at rest tends to remain at rest, a body in motion tends to continue moving in a straight line and at a constant velocity.* Our experience does not teach us the last truth, concerning the constant velocity, but observations upon the heavenly bodies, where friction and the resistance of the air do not interfere, have established that fact. For investigations in this line, Sir Isaac Newton is to be remembered.

Ganot's physics defines impenetrability as "that property in virtue of which two portions of matter cannot at the same time occupy the same portion of space." But states further that "strictly speaking, this property applies only to the atoms of a body," since "in every body there are interstices or spaces unoccupied by matter." Without attempting, however, to be very exact, we find it convenient to speak of matter as being capable of filling a given portion of space and excluding other matter from the same space. This is too familiar to require mention in case of solids and liquids, but it is of interest to notice that the same is true of gases, and that a bottle full of air or other gas may exclude water or other sub-

stances from entering until the air be either removed or its molecules forcibly crowded nearer together.

We quite as often find it convenient to speak of the penetrability of matter by reason of its numberless pores, or spaces among its molecules. Tait assumes that the molecules do not occupy so much as five per cent of the whole space within a body of matter. In many instances it requires a good deal of force to crowd molecules into this unoccupied space. Certain substances will, however, receive readily into their pores molecules of another kind than themselves. It is very difficult to prevent wood from absorbing water. To protect it against this action we are at great pains to keep it coated with oil, shellac, varnish, paint, etc. Wood will absorb water until it becomes too heavy to float in water. Hence the bottoms of lakes are strewn with fallen forests which once grew upon their shores. Vessels loaded with lumber become water-logged during long storms.

Brick partitions are placed in cisterns to act as filters, the water passing through the pores of the brick. Blackboard crayon absorbs gases and liquids in considerable quantities. Charcoal does the same to a very much more marked degree. Earthenware is glazed to prevent this action. Unglazed earthenware makes very good filters. Rocks are broken up by the freezing of the water which they have absorbed into their pores. This is illustrated by the disintegration of the brown stone fronts of New York buildings. Most metals absorb mercury into their pores. A clean piece of zinc will take in mercury until it dissolves in the liquid which it has absorbed. Allowing mercury to pass into the pores of a metal is called amalgamating the metal. It is sometimes done to prevent the action of other liquids upon the same metal. Iron is

protected in the same way by dipping it into melted zinc. This is called galvanized iron, although the name is misleading. The galvanizing of iron, the amalgamating of metals, and the oiling of floors and furniture all are similar processes and have the same purpose, namely, to fill the pores and prevent other substances from entering.

The artificial mineral waters have eight to ten times their volume of carbon dioxide gas forced into their intermolecular spaces. Cold water will absorb about a thousand times its own volume of ammonia gas. This is the ordinary ammonia water. Water absorbs nearly five hundred times its own volume of hydrochloric acid gas. This is the convenient form of the commercial acid. The metal palladium, at a red heat, will absorb nine hundred times its own volume of hydrogen gas.

An ordinary brick immersed in kerosene oil will quickly give out an eight-ounce bottleful of air and take in that amount of the oil. If the brick is then put in a stove or fireplace, it will support a flame for a considerable period, after which it may be recharged and the operation repeated. Use is sometimes made of this when there is a scarcity of other fuel.

PROPERTIES OF MATTER (CONTINUED)

EXPERIMENTS

Compressibility. — Push down piston of bicycle pump, holding finger over outlet. Release finger slowly. What happens to air within pump?

Elasticity. — Stretch and release rubber band. What changes in length and thickness do you observe? What caused rubber band to resume its original form? Slightly bend and release long slender glass tube. What temporary changes in form occur? What caused tube to resume its original shape? Fasten crosspieces to long dowel rod. Twist rod by crosspieces and then release. What caused rod to resume its original shape?

Tenacity. — Let two pupils grasp ends of sheet of writing paper held between leaves of two books. Pull until paper breaks across. Why is such great force required to tear the paper? Suspend glass plate in horizontal position from thin elastic strand. Lower plate until it touches surface of water in a dish. Attempt to separate and note effect on rubber band. Why was such great force required?

Malleability. — Hammer a lead shot or piece of copper wire flat and very thin. Illustrate extreme malleability by gold leaf.

Ductility. — Holding with both hands a piece of glass tubing, heat middle over flame. When red-hot, remove from flame, and quickly draw out into fine tube. Illustrate extreme ductility by platinum wire.

Hardness. — Test hardness of following substances by scratch method, arranging in order of hardness: copper, glass, lead, marble, mica, quartz, slate, steel.

Brittleness. — Test, by hammering, brittleness of various substances, *e.g.* glass, chalk, brass. Break piece of watch spring and heat to redness in flame; then cool slowly. Attempt to break as before. What change in properties of watch spring?

Since matter has intermolecular spaces, it must of necessity be compressible. That is, some of its own molecules may be forced into the vacant spaces among the neighboring molecules. The singular thing is that,

since the spaces are very much larger than the molecules themselves, matter should resist compression as much as it does, and when the compressing force is removed the matter tends to return to its original volume. This tendency is called elasticity.

The various forms of matter differ very greatly as to their compressibility and elasticity. Liquids and solids yield only slightly under very great pressure, but air and other gases are readily compressible and all to the same degree. They are also all equally elastic. Their compression is not like that of putty, which does not recover its volume again, but like the coiled spring represented in Fig. 1, in which *a* shows the spring with a weight upon it. The spring is exerting an upward push, or tension, equal to the downward pull of gravity upon the weight. *b* shows the spring expanded when the weight has been removed. So gases exert a tension always equal to the pressure upon them, but, unlike coiled springs, as pressure is removed they expand proportionately *without limit.* Metal springs lose some of their elasticity if compressed too much or too long, but gases are always perfectly elastic.

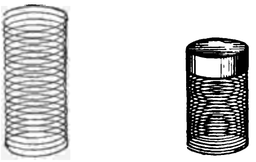

FIG. 1.

If matter is composed of molecules with vacant spaces much greater than the molecules themselves, and if the molecules move constantly to and fro, touching each other only when they for an instant come into collision, how is it that matter is able to retain any form at all as it does in solids; and how may it have such properties as tenacity, hardness, malleability, ductility, and brittleness? When confronted by this difficulty, it is natural that a reasonable person should withhold belief in the molecular

theory of the constitution of matter, but all inquirers do at length adopt the molecular theory.

The universe contains many suns and worlds. They are all in motion. They are not in contact with each other and yet they are arranged in groups as, for example, our own solar system, which is composed of the sun and eight principal planets, with a very large number of smaller ones. Many of these planets are accompanied by smaller bodies called satellites. All the members of the solar system are in constant motion, and yet they remain associated together as a group. This force, which holds worlds together, we shall learn to call gravitation.

There is a similar force among molecules which holds them in the groups which we call bodies of matter. Some of these groups of molecules, the solids, hang together with great tenacity. Among the solids the metals are conspicuous for this property, and among metals steel surpasses all the rest; on this account it is the most useful of all. Some solids resist better than others any attempt to separate molecules from their neighbors, as we learn by trying to scratch the surface. The slightest scratch made upon a pane of glass is in reality a furrow made among the molecules of the glass. This may be done by a diamond, or a quartz pebble, but cannot be done with a pin. The pin, however, will scratch tin or lead, and hence we say that glass is harder than tin or lead. It is harder than any of the metals. It is also more brittle than any of the metals, and yet we cannot say that brittleness is dependent upon hardness, for sealing wax, sulphur, and numerous other things which are not so hard as most of the metals are far more brittle. Molecular forces must account for brittleness in some way which we shall not attempt to explain. It is a matter of common experience

that if we increase the hardness of a substance, we usually increase also its brittleness.

A most interesting illustration is found in the tempering of edged tools. A knife blade which may be so soft as not to cut wood without seriously dulling itself, may be hardened by heating and suddenly cooling it so that it will keep sharp while cutting the hardest wood. It will, however, be noticed that as its hardness increases it grows more brittle, and hence the edge will be more liable to nick with hard usage. Fine tools can be used only by good mechanics.

When glass tubing is heated in bending and allowed to cool rapidly, it hardens and becomes brittle and is liable to crack. If, however, it is held in the smoky flame and allowed to cool slowly, it will be found to be much less brittle. This process is called annealing the glass. Lamp chimneys may be made tough by heating them in a very hot oven and then allowing them to cool slowly as the oven cools.

Molecular forces must account for malleability which enables some substances to hang together when hammered out into thin sheets. Thus gold may be made into leaves so thin that a pile of three hundred thousand of them would be only an inch thick. Gold when it is made as thin as that becomes transparent.

Molecular forces must account for ductility which enables some substances to hang together when drawn out into very fine threads. Thus platinum may be drawn into wire so small that fifty thousand turns may be laid in one layer upon a spool an inch long.

MOLECULAR FORCES

Experiments

Cohesion. — Carefully clean plane surfaces of two pieces of lead by rubbing on fine sandpaper or emery cloth laid flat on table. Press surfaces together with a twisting motion. What causes them to hold together? Carefully float needle on tumbler full of water. Note depression in surface film.

Adhesion. — Illustrations: glue, putty, solder, electroplating.

Capillarity. — Place vertical several clean glass tubes of various diameters in colored water. Note height of water in different tubes. In which tube does water rise highest? Note shape of surface of water inside and outside of tubes. Does the water wet the tubes? Which is greater, the attraction of molecules of water for molecules of glass, or that of molecules of water for one another? Repeat, using clean tubes and mercury instead of water. Note height of mercury in different tubes. In which tube does mercury stand at lowest level? Note shape of surface of mercury inside and outside of tubes. Does the mercury wet the tubes? Which is greater, the attraction of molecules of mercury for molecules of glass, or that of molecules of mercury for one another?

Conditions of Solids: Crystalline and Amorphous. — Suspend string in tumbler containing hot saturated solution of alum. Allow to stand quietly for several days. Note changes. Repeat, using potassium bichromate or copper sulphate. Examine lumps of sugar, common salt, rock candy, snow flakes, frost figures, etc., using magnifying glass when necessary. What structural peculiarity do you notice in each case? Examine resin, putty, glue, glass, wax, paraffin. How does the structure of these substances compare with that of the substances mentioned above?

A general term for the attraction which exists among the molecules of a substance is *cohesion*. It is very manifest in all solids, but not so evident in liquids. Indeed, it is so unusual to notice cohesion in liquids that quicksilver, as it rolls about in globules exhibiting its cohesion, is a curiosity. Water, however, acts in precisely the same manner upon an oily surface, and would act so upon all surfaces if

cohesion alone operated. We shall find it convenient to use the term *cohesion* only for the attraction between molecules of the same kind, and employ a new term, *adhesion*, for the attraction between molecules of different kinds.

It is a matter of common experience that water clings to, that is, adheres to most substances. Now suppose we touch the surface of some water with the end of a clean lead pencil (see Fig. 2, *a*), then raise it a little as at *b*. We find that water both clings to the pencil (adhesion) and to the body of water itself (cohesion). If now we raise the pencil still farther, as at *c*, we have proof that the adhesion between the pencil and the water is greater than the cohesion between water and water. For a drop of water has pulled away from the mass below and clings to the end of the pencil. Notice that at *b* the water under the end of the pencil assumes a dumb-bell shape. The upper half of this forms the drop of water upon the end of the pencil *c*, while the lower half breaks away and is mingled with the water below.

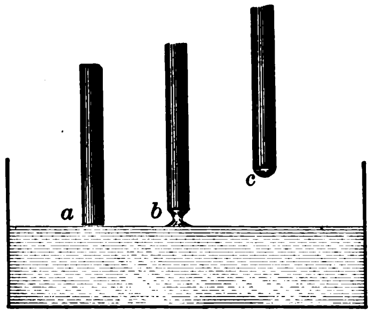

FIG. 2

A drop of water upon a clean plate of glass spreads about and forms a thin film, as would seem natural, since both the weight of the water and the adhesion operate together to crush down the drop as thin as possible. If we turn the plate bottom side up, the water still clings to the glass, showing that the adhesion between the glass and that water which is nearest to it is not overcome by the weight of the water. If now we wipe a plate of glass

with an oily cloth, spreading over the surface of the glass never so thin a layer of oil, the water behaves as the quicksilver did, that is, it stands up in round drops. We explain this by saying that there is cohesion among the molecules of water pulling them all toward one another so that they are crowded into round drops. We may observe further, that the cohesion is so strong that the drops are scarcely at all flattened by their own weight. If now we invert the plate, the drops will no longer cling to the glass, but will fall freely through the air, and while falling will maintain the spherical shape.

Rain falling in drops illustrates cohesion.

Whenever water wets or clings to the surface of any substance, it illustrates adhesion. It further illustrates the fact that adhesion in these cases is greater than the cohesion in the water. Water does not wet a paraffin candle, because the cohesion in water is greater than the adhesion between water and paraffin. For the same reason mercury does not cling to most substances. It does, however, exhibit adhesion for the clean surface of many metals.

It is evident that molecular attractions operate through infinitesimal distances. If we break a piece from a mass of iron, we cannot again bring the piece near enough to the mass so that it will cohere. If, however, we melt both and put them together in the liquid state, cohesion will make the union perfect, or we may soften the surfaces by heat, rendering them plastic, and then press them together. The molecules may thus be brought near enough to one another for cohesion to operate. This is called *welding*.

Soldering is a similar process, and the most essential part of the preparation for it is thoroughly to clean the surface of the metal so that nothing, like oil, etc., may interfere with adhesion. We then choose some metal that

is easily melted so that with a hot soldering iron we may bring about the adhesion.

Adhesion may be illustrated as in Fig. 3, *a*, which represents a thick glass tumbler held so that a small stream of water passing over the edge adheres to the side all the way down. At *b* the same tumbler is represented after the edge has been oiled. Coffee pots and milk pitchers which trouble in this way may be made to deliver well by touching their lips with a little butter.

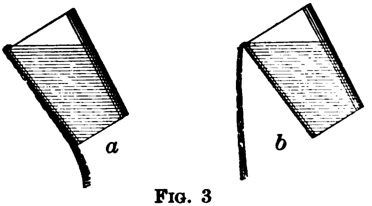

FIG. 3

When a clean glass rod is placed in water, as shown in Fig. 4, adhesion between the glass and the water will cause molecules of water to creep up the glass a short distance, and by cohesion these molecules will pull up other molecules until a visible mass of water is piled up around the rod. The same thing happens also at the sides of the vessel. If, instead of a rod, we use two plates of glass brought very near together, or a glass tube of sufficiently small bore, adhesion and cohesion will operate to raise the water to a considerable height — say two or three inches in a tube whose bore is no larger than a hair. Long ago an unnecessary term was constructed out of the Latin word for hair to designate this as a peculiar force called *capillarity*. It is still used when convenient, but no one needs to be misled by it into making a "distinction without a difference." The phenomenon is dependent upon adhesion and cohesion and upon nothing else.

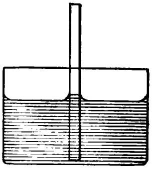

FIG. 4

Reflect how oil goes up lamp wicks; how mops take

up water from a floor; how ink is taken up by blotting paper; how the soil retains its moisture; how the candle flame melts its wax, and the liquid wax creeps up the wick to support the flame.

Table salt and many other substances, particularly the sal ammoniac used in electric batteries, form a solution with water which will creep up the side of a tumbler and over the top. The water evaporating will leave the salt incrusted upon the tumbler inside and outside. In the battery jar, where this would cause trouble with the electric current, we prevent this action of adhesion by coating the walls of the jar above the solution with paraffin.

When a paraffin candle or an oily glass rod is thrust into water, Fig. 5, adhesion between the water and the candle or rod being wanting, the molecules of water under the influence of cohesion alone are drawn toward each other and away from the candle. The same thing happens when a clean glass rod is thrust into mercury.

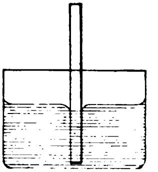

FIG. 5

Suppose we reduce the power of cohesion among the molecules of a solid, either by dissolving the solid in some liquid or by heating the solid until it melts to a liquid; suppose further that we allow these molecules to again come into the solid state by either evaporating the liquid in which they were dissolved or by cooling them, if melted, until they solidify. We shall find that it is the nature of a large number of substances when they solidify to have their molecules arrange themselves in masses of definite shape, like snowflakes, for example. These forms are called crystals. It is often possible with the eye to determine immediately what a substance is by the crystalline form it assumes.

In the case of some substances we may determine by the shape of the crystal whether it had been fused or dissolved. Shape of crystals may determine, to a certain extent, what the rocks are composed of. Substances not crystallized are called amorphous. Diamond is crystallized carbon, while the core of a "lead" pencil is amorphous carbon.

Not only beautiful forms, but also beautiful colors sometimes accompany the crystalline state. Copper sulphate crystals are a brilliant blue. If we heat in a test tube a crystal of this substance, we notice that drops of water collect upon the sides of the tube, the blue color disappears, and the crystal falls to an amorphous powder. If these drops of "water of crystallization," as they are called, are allowed to trickle back upon the powder, minute crystals quickly form, and the color also returns. Some substances, like iron sulphate (copperas), lose their water of crystallization without being heated. This is why the substance slowly loses its green color, and gets into the state of a powder on exposure to the air. Such substances are said to *effloresce*.

When molecules arrange themselves in crystalline forms, they require more room. This is why water will break a bottle when it freezes, or crystallizes, in it. This also explains why ice floats in water; being expanded by crystallization it is lighter than water. Only metals, such as iron, bronze, type metal, etc., which crystallize when they solidify, are cast in molds. Others contract on cooling from the melted to the solid state, and so do not take a good impression of the mold. Such metals, as, for example, gold and silver coins, are stamped, that is, forced while cold by great pressure into the mold, or die, as it is called in this case.

GRAVITY

Experiments

Center of Mass. — Suspend irregularly shaped board or cardboard (about 8 × 10 inches) and plumb line by pin stuck through one corner, as shown in Fig. 8. With pencil, trace direction of plumb line. Repeat with cardboard suspended from at least two other corners. Try to balance cardboard horizontally on pin point placed at intersection of these lines. Try to balance at other points on cardboard. Account for results. In what state of equilibrium was cardboard when suspended by pin? When supported on pin at intersection of lines? When supported on pin at any other point? With cone placed on its base, point, and side in turn, illustrate the three states of equilibrium. How do relative positions of support and center of mass determine stability?

We have thus far spoken of attractions which operate through exceedingly small distances — between the molecules. And now we come to what is called the attraction of gravitation, which operates between all forms of matter in the universe *however great the distance may be.* It is not peculiar to the earth, though we shall presently see why we are accustomed to attribute such special importance to the earth's attraction. The attraction which the earth exerts upon a substance is proportional to the mass of that substance. That is why we determine the mass of a body by weighing it. The act of weighing is simply measuring the attraction of gravity for a body. The body is attracted by other worlds, but, because of their great distance, their attraction is insignificant as compared with that of the earth. The second part of the law is that the attraction of gravitation varies inversely as the square of the distance. In order to get an idea of what this means, we need to give attention to the geometric representation in Fig. 6, which will explain a fact con-

cerning not only gravitation, but also concerning magnetic and electrical attractions and the intensity of heat and light.

Figure 6 exhibits the fact that a cross section of a pyramid at *c*, being *twice* as far from the apex as the section at *b*,

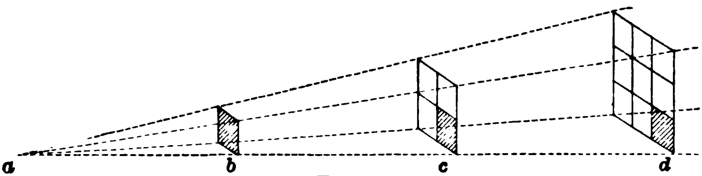

FIG. 6

has *four* times the area of *b*, and one at *d*, being *three* times as far from the apex as *b*, has *nine* times the area, etc.

Now suppose a source of light were situated at *a* and that it cast a certain amount of light upon *b*. Remove *b* and it will cast its light upon *c*, which being spread over four times as much area must be only one quarter as intense, or if its light falls upon *d*, three times as far away, it will be one ninth as bright. If the surface were four times as far away, the intensity of the light would be inversely proportional to the square of the distance, that is, one sixteenth as bright.

If a hot body were situated at *a*, the same statements would hold good for the relative intensity of the heat received at *b*, *c*, *d*, etc.

If a magnet were situated at *a* and a piece of iron held at *b*, *c*, and *d* successively, the attraction between the iron and magnet would decrease likewise, as 1, $\frac{1}{4}$, $\frac{1}{9}$.

Now this is the truth concerning gravity also, and we may apply it to show that weight does not always determine the amount of mass in a given body. Suppose a man, situated at *b* (Fig. 7) on the surface of the earth,

weighs 180 pounds. This 180 pounds is the sum of the attractive forces between each molecule in his body and each molecule in the earth. The attractions between him and those portions of the earth which are near him are vastly greater than those between him and those portions upon the remote side of the earth. The average distance between him and the earth, as a whole, is the radius of the earth (4000 miles). Now suppose this man were removed to *c*, twice as far from the earth as a whole (8000 miles from the center), he would weigh one quarter of 180, or 45 pounds. If he were removed to *d*, three times as far from the center of the earth (12,000 miles), he would weigh one ninth of 180, or 20 pounds. The moon is 240,000 miles from the earth. If this man were transferred to the moon, he would be about sixty times as far from the center of the earth as we are, and his attraction *for the earth* would be $(\frac{1}{60})^2$ or $\frac{1}{3600}$ of what it was originally — that is, less than one ounce. His attraction for the moon would then probably be called his weight. But this would not be 180 pounds, for two reasons. First, *the attraction of gravitation varies as the mass.* The earth's mass is eighty-one times that of the moon, hence if the man were as far from the moon's mass as he is from the earth's, when on its surface, he would weigh not 180 pounds, but $\frac{180}{81}$, or $2\frac{1}{5}$ pounds. Second, *the attraction of gravitation varies inversely as the square of the distance.* On account of the moon's relative smallness he could get nearer to it than he could to the earth. The square of the moon's radius is one fourteenth of the square of the

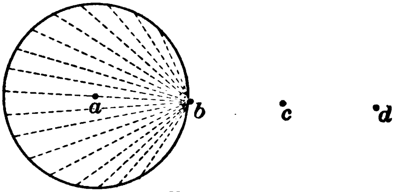

FIG. 7

earth's radius. Hence he would weigh upon the surface of the moon 14 times $2\frac{1}{5}$, or about 30 pounds. By the same process of reasoning, we find that he would weigh upon the surface of the sun about two and a half tons.

This discussion has been protracted for the purpose of showing clearly that the weight of a body would not be, *under all circumstances*, a measure of its mass. Whether, however, we ascend the highest mountain or descend into the deepest mine; whether we visit the equator or the poles, we are unable to change our distance from the earth, as a whole, sufficiently to effect any appreciable change in weight, and hence, so long as our distance from the earth remains constant and the mass of the earth remains constant, we may find it practicable to measure the mass of objects by their weight.

It must be remembered that the earth has no mysterious power of attraction located at its center, or elsewhere, which differs from that of any other body. Gravitation depends solely upon *mass* and *distance*. It does not vary with *kinds* of material, nor is its action interfered with by the interposition of any kind of material. No substance can be said to be opaque to it, or act as a screen for it. Nothing can reflect it, deflect it, increase or diminish it. It acts instantaneously over all distances.

The impression that up is away from the center and down is toward the center of the earth, would depart from us if we could get away from the earth itself, and we should readily relate these terms to any other heavenly body that we might approach. A person transferred to the moon would, no doubt, regard *down* as toward the center of that body. On his journey thither he would start *upward* from the earth. Imagine his bewilderment at that point of his journey where *up* should become *down*

without changing direction. Imagine further his sensation when, having arrived at the moon, he finds that on account of reduced weight, he can make a running jump over an object as large as a two-story house.

If we suspend a ball by a string, gravity causes it to point toward the center of the earth, because the earth is nearly uniform in mass. Since this gives us our direction of *up* and *down*, we call it a plumb line.

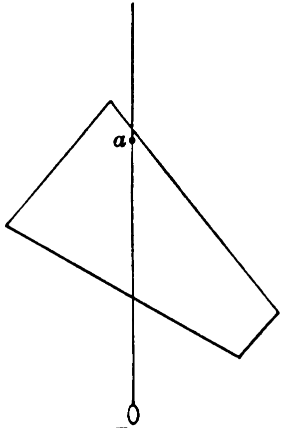

FIG. 8

If we suspend an irregular-shaped board from a string attached at *a*, Fig. 8, and suspend a plumb line from *a*, gravity will cause the board to arrange itself so that equal portions of its mass shall be on either side of the plumb line. The attraction between the earth and one portion is equal to that between the earth and the other, and these forces are balanced. If we saw the board along the line of the plummet, we shall cut it into halves. Instead, however, of sawing it into halves, suppose we mark upon the board the line of the plummet, then suspend the board from any other point, as *b*, Fig. 9, and mark again the line of the plummet. Then the two lines, *ac* and *bd*, each divides the board into halves, and their point of intersection *o* is the center of the whole mass, or center of gravity as it is called. The board may be suspended from a string

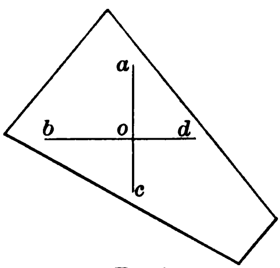

FIG. 9

attached at *o*, or balanced upon a pin point placed at *o*, and we shall find that the attraction of gravity is equal for all parts of the board arranged around this point, and either side of the board will remain up or down as placed, thus exhibiting indifferent or *neutral equilibrium*. If the board is suspended from any other point than the center of gravity, it will come to rest only in such a position that the center of gravity may be directly beneath the point of support, which is called *stable equilibrium*. Every attempt to bring any body to rest with its center of gravity above the point of support, provided the point of support is a point, must be a failure. The only way to bring about a state of equilibrium with the center of gravity higher than the point of support, is to increase the *point* of support to an area or *base* of support, and this sort of equilibrium is more or less unstable, according to the size of base and the distance of the center of gravity above the base. The child gets a practical knowledge of unstable equilibrium while he is learning to walk. He finds that to go on "all fours," thus increasing his base of support and lowering his center of gravity, is the method of making more stable his equilibrium. Note that the Eiffel tower spreads its feet; that a load of hay is more unstable than a load of earth; how walking on stilts affects one's equilibrium; that lead in the yacht's keel carries its center of gravity below its base of support. Note in all equilibrium toys the tendency of the center of gravity to get below the point or base of support.

THE PENDULUM

EXPERIMENTS

Pendulum. — Swing through small arc four pendulums of same length, but with bobs of different substances (glass, wood, brass, iron). What effect has the material of which it is made upon the time of vibration of pendulum? Swing pendulum through small arc (5°). Note number of vibrations made in 30 seconds. Swing through 10°. Note as before. What effect has a slight difference in arc through which it swings upon time of vibration of pendulum? Swing successively a 9-inch, 36-inch, and an 81-inch pendulum. Count the number of vibrations made in each case in 30 seconds. What relation between length and time of vibration of a pendulum? (Note. Length of pendulum is distance between the point of support and center of mass of bob when suspended by slender string.)

If the plumb line referred to above be pulled out of the vertical direction, the attraction of gravity pulls it back toward the vertical position. A body in motion tends, by its inertia (p. 10), to continue moving until stopped by a sufficient force. Hence this pendulum swings past the point of stable equilibrium, the lowest point in its arc, and rises on the other side until stopped by the resistance of the air through which it moves and by the contrary pull of gravity. This latter force then starts it in the opposite direction to repeat its excursions until friction and the resistance of the air shall bring it to rest. But the interesting fact to note is, that although the path of each swing is shorter than the one before it, the *time* of the swings is not shortened. This fact was first discovered by Galileo in 1583, while he mingled the study of physics with his devotions in the cathedral at Pisa, by watching the swinging of a bronze lamp suspended from the ceiling. The statement of this fact has been crystallized in our language in the following form. *The time of vibration*

of a pendulum is independent of the amplitude of the arc. It is also independent of the weight of the bob, which we may hang upon the plumb line, but is dependent entirely upon the *length* of the pendulum.

Certainly the fact that a short pendulum vibrates quicker than a long one is a matter of universal observation, but *the ratio of length to time of vibration* is observed by few. This is, however, the most useful portion of our knowledge of the pendulum. If we would double the time of vibration of the pendulum, we find that its length must be increased fourfold. If we would multiply its time by three, we must multiply its length by nine.

A pendulum about 39 inches long at New York will occupy one second for each swing. A pendulum that would occupy two seconds for each swing would need to be four times 39 inches, or 13 feet long, and a pendulum which would occupy half a second for each swing would need to be $\frac{1}{4}$ of 39, or $9\frac{3}{4}$ inches long. Since it is the force of gravity which causes the pendulum to swing, changes in this force will change the time of the pendulum. We have learned on page 26 that this change is slight, but it affects pendulum clocks, and necessitates their regulation according to locality.

MACHINES

Experiments

Levers. — Balance yardstick on fixed axis with weights. Find numerical product of each weight by its distance from fulcrum. How do products compare? Repeat, using unequal weights. Substitute finger pressure for either weight, thus showing that either weight may be considered as a force. Balance yardstick with weight and spring balance. Find products and compare them. Repeat, exchanging positions of weight and balance. Find products and compare as before. Generalize results obtained in form of an equation.

Pulleys. — Arrange single fixed pulley and equal weights. Arrange single movable pulley with weight and spring balance. What relation exists between load and force required to support it? Arrange two double pulleys. What relation exists between load and force required to support it? Compare product of force multiplied by distance through which force moves with that of load multiplied by distance through which load moves.

Wheel and Axle. — Arrange wheel and axle. Find numerical product of weight attached to wheel multiplied by radius of wheel. Find the numerical product of weight attached to axle by radius of axle.

Inclined Plane. — Arrange smooth board, about two feet long, with loaded car and spring balance. Incline board at various angles and observe different readings of spring balance. What effect has inclination of board on force required to hold car in place? Support one end six inches above table. Assuming that car were pulled all the way up plane, through what *vertical* distance would it be lifted? Through what distance does force act? What is relation between product of weight multiplied by weight distance and that of force multiplied by force distance?

Explain wedge as modification of inclined plane, and illustrate by ax and penknife. Show application in splitting wood. Explain screw as another modification, illustrating by letterpress, bench clamp, vise, jackscrew.

Balances swing back and forth somewhat as a pendulum does. The most important consideration is that the center

of gravity of the system should be below the point of support. In the balances represented in Fig. 10 the point of support is at *f*, and the center of gravity, when the weights are in the scale pans, is at *c* in the pointer. The position of *c* varies up and down somewhat with the load in the scale pans.

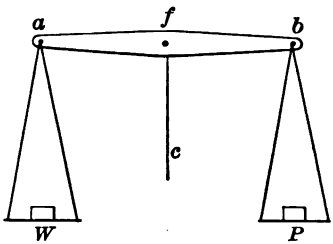

FIG. 10

If the points of support *a* and *b* for the scale pans are equally distant from *f*, we find that equal weights in the two pans will balance one another; but if the arms of the balances are unequal, the longer arm will require the lighter weight. For weighing as small masses as the grocer does there is no inconvenience in having iron weights enough to balance the articles weighed; but in weighing large things like loads of hay and coal, it is necessary to have some device for making a comparatively small amount of iron balance the large mass to be weighed. This is done by lengthening the arm of the balance upon which the iron weight is hung. We find that if we make the arm *bf* twice as long as *af*, the weight *P* will balance twice its own weight at *W*. If *bf* is made three times that of *af*, *P* will balance three times its own weight at *W*. To make one pound balance twenty, it is necessary to give it an arm twenty times as long as the other. This is the principle upon which we construct steelyards, hay scales, or the platform scales on which one weighs himself, using an iron disk weighing perhaps a pound or two.

This, also, is the principle which a man uses when he wishes to move a heavy rock with a crowbar. Thus, in Fig. 11, *W* represents a heavy rock, *ab* the crowbar.

Another rock *f* is crowded under the bar close to *a*. The man applies his weight to the bar at *P*, and, because he has the longer arm *bf*, his weight, though very much less than that of the rock, may balance or even lift it. If *bf* is twenty times as long as *af*, a downward pressure of 100 pounds at *b* will cause an upward pressure of 2000 pounds on the rock *W* at the point *a*. Another name for the crowbar is *lever*. The rock *W* is called *the weight*, the rock *f* the *fulcrum;* and, inasmuch as we propose to develop from this instrument ideas concerning more complex machines, where steam, wind, or horse power may be applied at *P* instead of the weight of a man, it will be convenient to use the general term *power* for that.

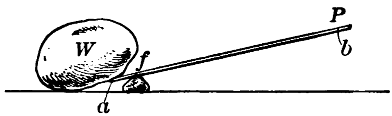

FIG. 11

Manifestly the crowbar will frequently be used as represented in Fig. 12, where the fulcrum is at the end *f* of the bar, and *P* is applied in the upward direction to lift the rock *W*. In this case, also, if *bf* is twenty times as long as *af*, a pull of 100 pounds at *P* (which might be indicated by a spring balance) would cause a pressure of a ton at *a* upon the rock *W*.

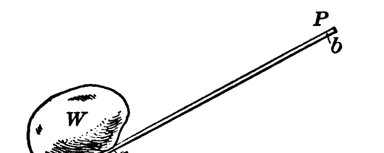

FIG. 12

To distinguish this method of using the crowbar from that represented in Fig. 11, this is sometimes called a *lever of the second class*, while that is called a *lever of the first class*. There is still a third way in which the man occasionally uses his crowbar, represented in Fig. 13.

He pushes with his left hand at *f* and pulls with his right hand at *b* to move a light stone at *a*. This represents a *lever of the third class.* The habit of distinguishing levers by classes has become almost obsolete.

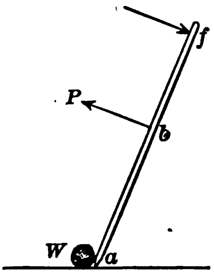

FIG. 13

The seesaw is an illustration of a lever. If the middle point of the bar is fixed so that both arms remain the same length and the same weight, a man weighing 150 pounds at *b*, Fig. 14, will balance a boy weighing 75 pounds at *d*; or, if he sit at *a*, he may balance two such boys at *d*.

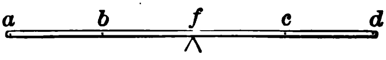

FIG. 14

For cutting metal we use long-handled shears in order to overcome the great resistance by means of levers. The tailor has shears with short handles and long blades in order that he may cut fast. If, however, he has a hard place to cut through, he moves it near to the fulcrum or rivet of his shears so as to increase his leverage.

Figure 15 may represent the conditions when two persons *a* and *b* carry a weight *f* suspended in the middle of a stick. The arrows indicate the directions of the forces. They each carry half the load, because the lever arms are equal. But if the weight is shifted, as is represented in Fig. 16, so that the arm *bf* is twice that of *af*, *a* must carry twice as much of the load as *b*.

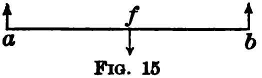

FIG. 15

Horses attached to either end of a whiffletree, as *a* and *b* in Fig. 15, must each pull half the load *f*. But when a young colt is first put in harness, he is sometimes hitched up with a horse, as represented by Fig. 16,

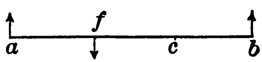

FIG. 16

so that the colt may have the longer end of the whiffletree.

Figure 15 may represent two persons, *a* and *b*, carrying a log of uniform thickness. Its weight might be represented as concentrated at its center of gravity, which in this case is at the middle of the log. Each person thus carries an equal share, because the lever arms are equal. Figure 16 may represent two persons carrying a log which is larger at one end than at the other. The center of gravity may be at *f*, in which case *a* would carry much the larger share. If *b* would do his share, he must move his position to *c*.

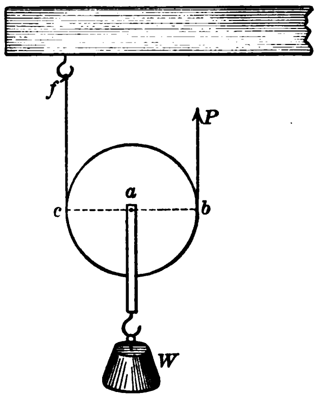

FIG. 17

If we look upon Fig. 15 as the diameter of a wheel, and describe a circle about this diameter, as in Fig. 17, it becomes manifest that the pulley works on the same mechanical principle as the lever. If the rope is attached to some support at *f*, and passing halfway around the pulley extends to *P*, a weight of 200 pounds at *W* will be sustained by a force of 100 pounds at *P*, because the lever arm *bc* is twice the lever arm *ac*.

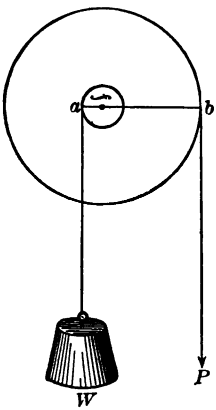

FIG. 18

If this wheel be supported by an axle, as represented in Fig. 18, and *P* operate upon a rope about the wheel, while *W* is hung upon a rope about the

axle, the mechanical advantage can be increased enormously, and is determined by the relative length of power arm and weight arm. Where is the fulcrum? What is the power arm as represented in Fig. 18? What is the weight arm? What is the mechanical advantage?

The claw hammer, Fig. 19, illustrates the principle of levers, and brings out the fact that the "*arms* of the lever" may not be arms of the *lever* at all. For to find the mechanical advantage of this instrument, we must measure the *air lines* between *a* and *f*, and also between *b* and *f*. But *a* and *b* rotate about the point *f*, and describe in the air circles such as are represented by the wheel and axle.

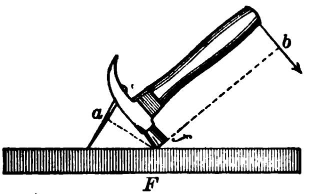

FIG. 19

The one simple principle to be remembered is that to determine the mechanical advantage we find the ratio between power arm and weight arm, which terms are interchangeable at convenience.

It will be interesting and profitable to find illustrations of the principle of levers in nutcrackers, the wheelbarrow, oar in rowing, candy or sugar tongs, sheep shears, action of muscles at various joints of the body, derrick, old-fashioned well sweep, elevators, belted and geared wheels, etc.

It is instructive to compare the force required to wind a clock with that required to stop it by obstructing its second hand, as may be done by a hair or piece of lint. Note the chain of cog wheels which give the mechanical advantage to the hair or piece of lint, and note, also, the fact that while the axle which carries the second hand moves around 60 times an hour and 1440 times in a day,

the axle to which the mainspring is attached moves around perhaps five times in a day.

Consider also the sewing machine. Compare the power applied by the feet with the slight obstruction at the needle necessary to hold the machine still. Compare also the speed of the needle with that of the treadle — about four or five to one.

In looking over all the illustrations we have had of levers, etc., it is true in every case that *what one gains in force he loses in speed.* If P, being half as great as W, is able to balance it when they move, P must move twice as far as W; or, being one third as great, it must move three times as far, etc. In devising any machine, therefore, we have to consider whether we wish speed at the expense of power or power at the expense of speed. This is well illustrated by the two kinds of shears mentioned on page 34. In the case of the sewing machine, we want the needle to go rapidly, and we must, therefore, expend very much greater power with the feet than one could do with a finger on a needle. In the case of the clock mentioned above, we want an axle carrying the second hand to revolve 1440 times in a day, but we are unwilling to wind an axle of the clock more than five turns each day, hence we accept the inevitable consequence that we must use a proportionally greater force in winding.

The "self-winding" clock winds itself by means of a little electric motor operated by two battery cells in the clock. The motor has very little power, hence it is necessary that the clock should have a mainspring which winds very easily. Hence its chain of geared wheels must be a short one. Hence it must wind itself very often — usually every hour.

Compare the bicycle geared for high speed with that

geared for hill climbing. What is meant by the high gear and low gear on the automobile, and what relation do these bear to the power of the engine?

Every machine exemplifies two simple relations:

1. The product of power multiplied by power arm equals the product of weight multiplied by weight arm.

2. The product of power multiplied by distance through which power moves equals the product of weight multiplied by distance through which weight moves.

Thus, in Fig. 20, since the power arm bf is four times the length of the weight arm af, P must be one quarter as great as W in order to balance it. If P is 1 pound, W must be 4 pounds.

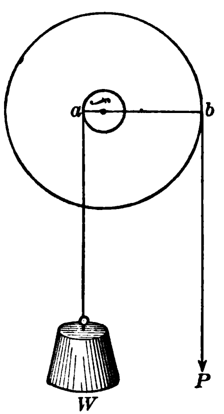

Fig. 20

$$P \times bf = W \times af$$
$$1 \times 4 = 4 \times 1$$
$$5 = 5$$

When P moves down, W moves up. When W moves 1 foot, P moves 4 feet. Hence

$$P \times \text{distance it moves} = W \times \text{distance it moves}$$
$$1 \times 4 = 4 \times 1$$
$$5 = 5$$

If one has a weight to lift greater than the power at his disposal, he will apply his power at P, Fig. 20, and be content to move the weight slowly. If he has sufficient power and desires speed, he will attach the weight at P and apply his power at W. This may suggest a method of gaining speed for a passenger elevator (see p. 58).

It is therefore manifest that P and W are interchanged arbitrarily, but the relationship expressed above must always hold good.

Nothing could be a more familiar truth than that the power required to move a load uphill varies with the grade. It seems probable that the enormous stones which were constructed into the pyramids of Egypt were elevated to their positions by rolling them up inclined planes of moderate grade. The simple principles stated for levers, etc., apply to inclined planes also.

Refer to Fig. 21 and suppose the hind wheel of the car *W* moves from *a* to *b*. It is manifest that *P* will at the same time move from *c* to *d*. But the vertical height which *W* has moved is *be*. Now we find that the ratio between *be* and *cd* is always equal to that between *P* and *W*. If the inclined plane has such a grade that *be* is half as long as *cd* or *ab*, 1 pound at *P* will balance 2 pounds at *W*, and if the grade is 1 to 3, *P* will balance three times its own weight at *W*; and from this we derive the same equation as on page 38; namely,

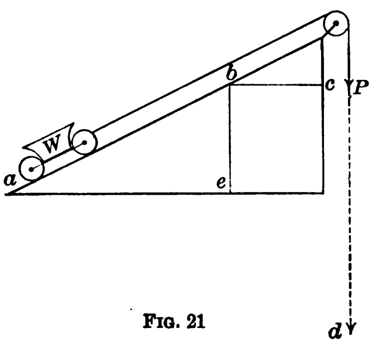

FIG. 21

P × vertical distance through which it moves =
W × vertical distance through which it moves.

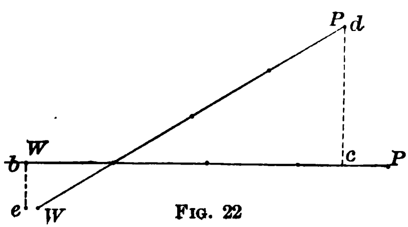

FIG. 22

This general equation states the fundamental principle of all machines, and is seen to apply to the lever, the wheel and axle, and the inclined plane by referring to

Figs. 22, 23, and 21, where in each case *be* represents the vertical distance through which *W* moves and *cd* represents the vertical distance through which *P* moves.

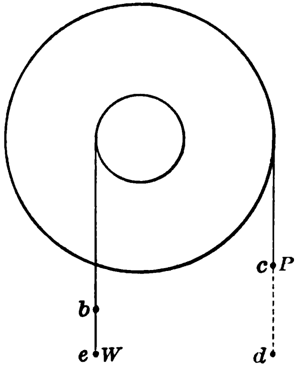

Fig. 23

Illustrations of the inclined plane as a machine for enabling a small power to do a large work will be found in the letterpress, the vise, the jackscrew, etc., where the thread of the screw is an inclined plane, and when this is combined with a lever, as in the case of the jackscrew, for example, it gives an enormous mechanical advantage.

The wedge, used in splitting logs, shows the great mechanical advantage of an inclined plane. Chisels, planes, axes, and all cutting instruments are illustrations of the inclined plane.

MECHANICS OF LIQUIDS

Experiments

Pressure. — With funnel, rubber tube, and pressure gauge containing water, measure pressures when surface of water in funnel is at depth of 2 inches, 4 inches, 6 inches, and 8 inches below surface of water in tall jar. What is the relation between pressure and depth? Arrange lamp chimney and glass or metal disk with string attached. Holding disk against lamp chimney with thread, force chimney into jar of water. Observe and explain behavior of disk. Fit wide-mouthed bottle with stopper, tube, and syringe bulb. Fill *entire* apparatus with water. Compress bulb. Repeat after placing heavy weight on rubber stopper. How do you account for behavior of stopper?

Fountain. — Arrange funnel, rubber tube, and glass nozzle. Fill with water, elevate, and then depress funnel. How do you explain action of liquid in each case?

Buoyancy. — Fill small tin can, having overflow tube near the top, with water until it runs over. Place block of wood, apple, or other small floating body in can, and catch water thus displaced. Weigh floating body in air and weigh water displaced. What relation between these weights? Fill can as before. Suspend small heavy body within can of water, and weigh water displaced; also weigh heavy body as it hangs in water, and weigh it in air. How much weight does body seem to lose when suspended in water? What is relation between this loss of weight and weight of water displaced?

Specific Gravity. — Weigh several heavy bodies in air and in water, and note apparent loss of weight in each case. Find how many times weight of displaced water is contained in weight of heavy body displacing it. Weigh bottle empty, then filled with water, then filled with kerosene. What is weight of the water? What is weight of the kerosene? How many times is weight of the water contained in that of the kerosene? What should we call the quotient?

All the phenomena of pressure in liquids are due to gravity, and the reason why they act in some respects different from solids is because their molecules are not so firmly bound by cohesion. Thus they exert upward pres-

sure or buoyancy, which is impossible in solids. A compact solid exerts a pressure only downward, but if it be composed of smooth particles, as sea sand, fine shot, pea coal, wheat, granulated sugar, or flaxseed, it may act to a slight degree as a liquid does, in producing pressure sidewise and upward. We build the side of a coal bin strong because the coal exerts a pressure sidewise. This would not be necessary if the coal were in one compact mass as it was in the mine. A bin that will hold twenty tons of egg coal may burst when twenty tons of pea coal are put into it, because the pea coal is much more like a liquid, in that it has freer motion among its particles. The side of the coal bin is more likely to burst near the bottom, because the pressure, being due to the weight of the mass, increases with the depth of the bin. A bin built as represented in elevation in Fig. 24 might show a bulging upward of coal at *a*. It certainly would do so and even run over if filled with fine shot, wheat, or rice. A bin is sometimes arranged like this for the feeding of hens. It keeps the grain clean and the supply constant. The bulging up and running over, if it occurs, is due to the pressure of the mass from behind. In the case of water the particles move so freely among themselves that the liquid will flow out at *a* quite as freely as it would from a similar opening sidewise at *b*, or even through a similar opening downward in the bottom, provided the depth of the liquid is such that the pressure from behind is the same in all cases. This may be illustrated by the apparatus shown in Fig. 25. If the bottle is filled with water and any two of the three openings *a*, *b*, and *c* be closed, it will empty itself down to the dotted line in the same

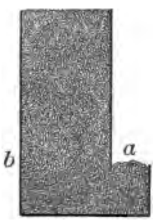

FIG. 24

time whether flowing upward at *a*, sidewise at *b*, or downward at *c*. This depends upon the liquid being a perfectly free-flowing liquid. It is not true of molasses, tar, or cylinder oil, for the same reason that it is not true of shot and sand. When a liquid is a perfect fluid, we may say that *the pressure at any given depth is the same in all directions*, and, since liquids are incompressible, *the pressure is proportional to the depth.*

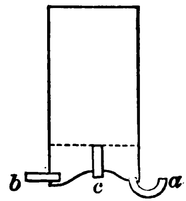

FIG. 25

A cubic foot of water weighs 62.5 pounds, and, since it is incompressible, or very nearly so, a cubic foot of water at the bottom of a tank full of water contains the same amount as one at the top, and hence if the tank is 10 feet deep, the pressure of water upon a square foot of the bottom must be 625 pounds (10 × 62.5). Suppose a vessel strikes a rock and breaks a hole in her bottom equivalent to 1 square foot. Suppose that while she is resting on the rock the tide falls, leaving her bare, and after the water has drained out the sailors tack a piece of canvas over the hole and make it water tight. When the tide rises again so that this broken place is 10 feet below the surface of the water, with what force will the water push upward to get in at the hole? Suppose the bottom of the vessel has 1000 square feet at an average depth of 10 feet below the surface, what would be the total upward push of the water? If she floats, what does the vessel and its cargo weigh? Objects which float have an upward pressure underneath them equal to the downward pressure of their weight. A convenient form of this statement is that *floating bodies displace their own weight of the liquid.* This is called the "principle of Archimedes." A Greek philosopher of that name first enunciated it.

A man whose weight is 180 pounds, and whose volume, when his lungs are full of air, is 3 cubic feet, falls overboard. He is unable to swim. If he keeps the water out of his lungs and stomach, may he float? If so, how much water must he take in to sink himself?

Things which float in water must be lighter than water, and things which sink must be heavier than water. The weight of a substance compared with the weight of water is called its specific gravity. If the specific gravity of granite is 2.5, a cubic foot of it weighs $156\frac{1}{4}$ pounds (62.5×2.5). When it is submerged in water the liquid lifts 62.5 pounds and hence a force of $93\frac{3}{4}$ pounds will lift a cubic foot of granite under water. By weighing a substance both in water and out of water, we may determine not only its specific gravity but also its volume. Suppose we find that a piece of iron weighs out of water 437.5 pounds and in water 375 pounds. The weight of the water which it dis-

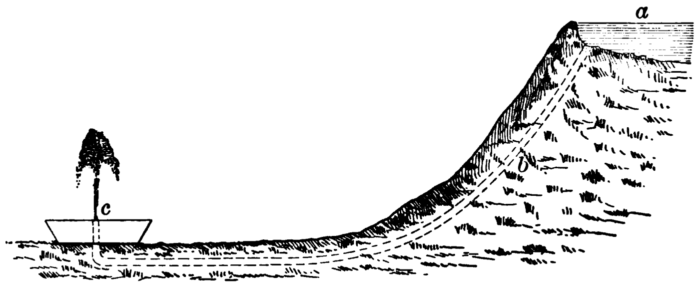

FIG. 26

places is 62.5 pounds. It is, therefore, seven times as heavy as water, and its volume is 1 cubic foot.

The upward pressure upon the bottom of a vessel may be illustrated by pressing a tin can, having a small hole in the bottom, down into water. The upward push is

distinctly felt, and evidence of it is also seen in the fountain which plays through the hole, driven upward by this pressure. Fountains usually operate for this cause. That is, there is water somewhere higher than the fountain nozzle which by its weight pushes the water up in a stream through the nozzle.

Figure 26 gives a suggestion of how a fountain in a city park operates. *a* is one of the city reservoirs which must always be in some high location. *b* is a pipe hidden underground which brings the water to the fountain *c*. The weight of the water in the pipe *ab* pushes the rest up in a stream from the nozzle *c*.

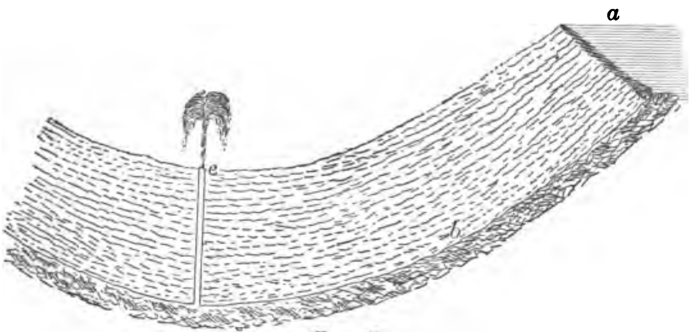

FIG. 27

Figure 27 suggests how artesian wells may operate. *a* is a lake situated upon high ground — perhaps a distant mountain. *b* is a stratum of gravel which is so closely overlaid with clay that water percolating from the lake through the gravel cannot rise in the valley below until it reaches the artesian well *c* which has been bored through the clay. Here it is pushed upward in a fountain by the weight of water in *ab*.

An electrician once boring into the floor of a house to run a wire made a hole in a water pipe which ran along

under the floor. When he pulled out his gimlet, the water spurted up in a fountain like an artesian well. The tank which furnished the pressure was in the garret, and the water in it was about 11 feet above this hole. A leak which at another time occurred in the water pipe in the cellar about 22 feet below the water in the tank spurted out with much greater force. We say that the water pressure, or the "head of water," was twice as great in the second case as in the first. Engineers have a more definite way of stating it. They speak of the pressure in pounds per square inch. If the head of water is $11\frac{1}{3}$ feet and the hole is 1 square inch, the pressure of water at the hole is found to be 5 pounds. A depth of water $22\frac{2}{3}$ feet represents a pressure of 10 pounds per square inch, and a depth of water 34 feet exerts a pressure of 15 pounds per square inch. The opening at the mouth of a kitchen faucet is equivalent to about $\frac{1}{3}$ of a square inch. (The cold water faucet is a little more and the hot water faucet a little less than this.) If the water in the tank is 34 feet above such a faucet, one may close his thumb over the mouth of the faucet and open the stopcock and hold back the water by pushing 5 pounds.

A hole bored with a half-inch bit (about $\frac{1}{5}$ of a square inch) in the bottom of a ship 11 feet below the water line will require only about 1-pound pressure to stop the inflow of water. It might be safely plugged with an ordinary cork. This pressure would, however, amount to 5 pounds upon a square inch, more than 700 pounds on a square foot, and more than 3 tons upon a square yard. We may put this truth in such a form that it will seem like a paradox. In Fig. 28, suppose the tube *ab* has a cross section of 1 square inch and

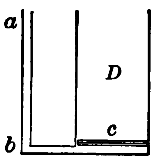

FIG. 28

that *a* is $11\frac{1}{3}$ feet above *b*. Then if the tube is filled with water, the pressure at *b* is 5 pounds. Suppose this tube to communicate with a tank *D*, which has a false bottom *c* that slides up and down, water-tight, and suppose the area of *c* is 1 square yard. The upward pressure upon *c* will be more than 3 tons (5×1296 pounds), and this pressure is exerted by a weight of 5 pounds of water in the tube *ab*. If *ab* were made $22\frac{2}{3}$ feet high, the weight of water in it would be 10 pounds, and the upward pressure upon *c* would be 12,960 pounds. If *ab* were 34 feet high, it would hold less than 2 gallons of water, but would exert a pressure of nearly 10 tons upon *c*. This pressure might be produced at *b* by a small pump with the same result at *c*. Since *D* has a cross section 1296 times as large as that of the tube *ab*, it must contain 1296 times as much water as *ab* when it stands at the same height in both. It would be necessary to fill *ab* 1296 times full of water in order to push *c* clear to the top of *D*, and hence what one would gain in power he would lose in time in this as with other machines.

Suppose the tank *D* to be filled with hay or cotton, and a top clamped upon it. By pumping water into the space under *c* it would be possible to exert a very great pressure upon the hay or cotton, and this might be used for baling such material. The name ***hydraulic press*** is given to such a machine. It has various forms and many uses. Suppose in the apparatus represented by Fig. 29 the opening through the stopcock *b* is $\frac{1}{10}$ of an inch broad and the diameter of the cylinder *D* is $4\frac{1}{2}$ inches. The corresponding areas are about as 1 to 2000. Therefore, if any perfect fluid is forced in through *b* with a pressure of 1 pound,

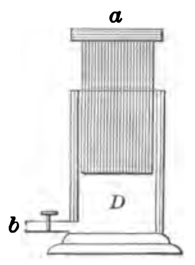

FIG. 29

it will exert an upward pressure upon the piston in the cylinder *D* of 2000 pounds, and each additional pound of pressure at *b* will balance an additional ton at *a*. Manifestly with such a machine one man could lift a locomotive even though we must allow a large loss for friction. The efficiency of such a machine depends upon the fact that in a perfect fluid pressure is transmitted without loss in all directions. This is about true in the case of water.

MECHANICS OF GASES

Experiments

Weight of Air: Buoyancy. — Exhaust air from large bottle or flask provided with rubber stopper, tubes, and pinchcock. Place on scale. Readmit air. Note and explain results.

Balloon. — Blow large soap bubbles with illuminating gas (or hydrogen) by connecting gas jet with clay pipe or thistle tube. Detach bubble. Explain results.

Atmospheric Pressure. — Plunge an upright tumbler under water. Invert tumbler and raise it until its mouth is just under surface of water. Observe level at which water stands within tumbler. Slide a cardboard or stiff paper cover under mouth of tumbler, holding cardboard or paper in place with finger. Remove finger from cardboard. Note and explain behavior of water in tumbler. Thrust a long slender glass tube ($\frac{3}{16}$ inch) into a jar or pail of water. Place a finger tightly over top of tube and lift tube from water. Observe results and account for them. Remove finger from top of tube and again account for results.

Barometer. — Fill with mercury a stout glass tube, about 33 inches long and $\frac{1}{4}$-inch interior diameter, sealed at one end. Tightly close open end of tube with finger and invert, placing end of tube in dish of mercury. Remove finger. At what height above surface of mercury in dish does mercury remain standing in tube? Why does not all the mercury remain there? How would height of mercury column be affected if this experiment were performed at top of high mountain? How if performed at bottom of deep mine? Why is barometer used to determine altitudes? Note and record barometric readings daily for one week. Do readings vary? Explain.

Siphon. — Bend a glass tube in form of letter J. Fill tube with water. Close long arm of tube with finger. Invert, and place short arm in glass of water. Remove finger. Observe and explain results.

Pumps for Liquids. — Construct models or make diagrams of lift and force pumps.

Air Pump: Exhausting. — Explain action by diagrams and by comparison with lift pump. Air-pump experiments: Open top receiver covered with sheet rubber or hand; Magdeburg hemispheres; closed receiver containing siphon bottles or partially inflated rubber bag.

Air Pump: Condensing. — Explain action by diagrams and by comparison with force pump.

Since the molecules of gases move among themselves even more freely than those of any liquid, they are the most perfect fluids we have; and, if they have weight, the principles of pressure stated for liquids in the foregoing section must apply to gases also. We may reason that gravity would operate upon the molecules of gases to give them weight as certainly as it does upon those of liquids and solids, but we need to make this appeal to our senses in order to appreciate the fact. Let us then consider what appeal the atmosphere makes upon our senses. We live at the bottom of an ocean of air, which behaves in many respects as an ocean of water does. When we move about, we push the air from before us and it flows in to fill the space behind.

If upon a perfectly calm day we move swiftly, as in an open trolley car, we plow through the quiet air, as fishes do through a quiet lake of water, and we seem to feel the air rushing past us like a wind. As we plunge through this air, we need to hold our hats to prevent its brushing them from our heads. If the cars should go much faster, — say a mile in a minute, — we would with great difficulty hold fast to prevent the air pushing us off the car. If one undertakes to swing rapidly a palm-leaf fan, he feels that the air offers much resistance to its motion. The fans which move the air through some of our large buildings for purposes of ventilation require 75 to 100 horse power. It is evident that air occupies space as certainly as water does, and that it is in a measure capable of preventing other substances from entering the same space with itself. One may stand upon an empty football and be lifted as the air is forced into it. In this case air literally crowds

the person out of the space which it is to occupy. We ride upon air by means of the pneumatic tires upon our bicycles, carriages, and automobiles. We sit upon air in air cushions and sleep upon it in air mattresses. Our various kinds of door checks have air cushions which prevent the doors from slamming.

In the popgun we have a good illustration of how air may serve as a medium with which to push things along. In Fig. 30, *ab* represents a goose quill, or a glass tube, *c* and *d* are plugs of potato or rubber which fit the tube tightly, *e* is a stick, or glass rod, which serves to push along the plug *d*, and the air between *d* and *c* serves to push the plug *c* which flies out with a loud "pop." *ab* suggests the cylinder of a pump, *d* the piston, and *e* the piston rod. This, however, will be mentioned later.

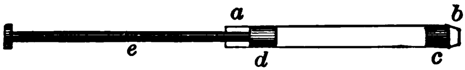

FIG. 30

In the air brakes used to stop our railroad trains, air is forced into cylinders and pushes against pistons which push brake shoes against the car wheels. The air brake enables the engineer or motorman from his position at the front of the train to control all the brakes on all the wheels of his train and to stop his train from full speed in a very few seconds. Forty years ago when an engineer wished to stop his train it was necessary for him to blow his whistle and call the "brakeman" of each car to put on the brakes of his own car, which was done, as it is still done on some freight trains, by tugging away at a wheel on the platform of the car which pulled a chain wound around its axle which pulled the brake shoes against the wheels of the car. Sometimes the train ran far past the station before all these men working together could stop

it. And there was a sorry time if the engineer suddenly saw some obstruction upon the track.

Railroad signals are sometimes operated by air pushed through long tubes. Bells are sometimes rung in various parts of a big hotel by air pushed through long tubes. Whistles are blown by air in speaking tubes. Mail bags and express packages are pushed by air through long tubes to the various parts of some of our cities, and in many stores the money which you pay for what you purchase at the various counters is quickly pushed by air through tubes up to the cashier's desk.

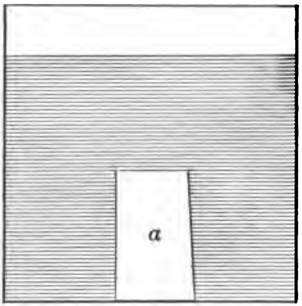

FIG. 31

When we need to work at the bottom of a body of water we put down an air-tight box open at the bottom and depend upon the air in the box to keep the water from entering to reach the workmen.

In Fig. 31, *a* represents a tumbler full of air inverted in a vessel of water. A wad of paper tucked into the tumbler will show, when it is lifted out, that no water has entered the tumbler. This tumbler may represent a diving bell or a caisson.

It is evident, then, that the invisible air and other gases occupy space and exclude other matter from the same space in the same manner as visible bodies do. If we lived at the bottom of the ocean, water would appear to us to have no weight because of the buoyancy of the surrounding water. In like manner, living as we do at the bottom of the atmosphere, air appears weightless. Probably every one at some time in life conceives the idea, more

or less vaguely, that it is the tendency of all gases to rise. Now the fact is that if any gas rises, it rises because of the buoyancy of the air, which is only another way of saying that the air has weight and a greater weight than the gases which rise in it. To say that gases tend to rise is analogous to saying that wood tends to rise in water. This ought not to leave with us the impression that these things are weightless.

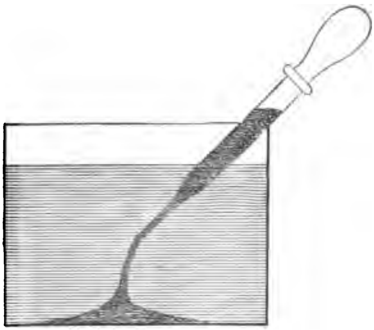

FIG. 32

Figure 32 shows how glycerine when slowly poured from a dropper tube into a tumbler of water falls directly to the bottom and spreads out as the bottom layer in the vessel. This is the way carbon dioxide gas behaves when it is poured into a vessel of air.

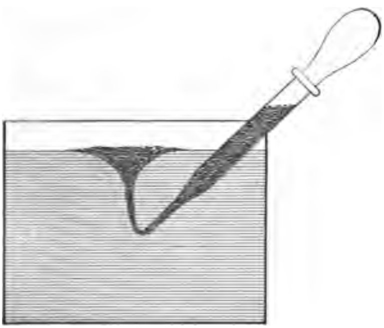

FIG. 33

Figure 33 shows how alcohol when slowly poured from a dropper tube into a tumbler of water rises directly to the top and spreads out as the top layer in the vessel. This is the way hydrogen gas behaves when it is poured upward into an inverted vessel of air. Such experiments tell us that carbon dioxide, air, and hydrogen all have weight, and they tell us something of their relative weight.

When we, living as we do at the bottom of the atmosphere, wish to determine how much air weighs, we proceed exactly as we would to find the weight of water under water, that is, by an indirect method.

Suppose we take a vessel having a capacity of a cubic foot and weigh it upon a spring balance. By referring to Fig. 34 we shall see that we are not directly weighing the air, but finding the balance of certain forces from which we may compute the weight of the air. Let the arrow *a* represent the pull of gravity upon the air in the vessel, *c* represent the pull of gravity upon the vessel itself, and *b* the buoyancy of the air. If now we remove the air from the vessel and weigh again, the loss in weight will give us the value of *a*. In this way we find that a cubic foot of air weighs about an ounce and a quarter, varying much with conditions of temperature and pressure.

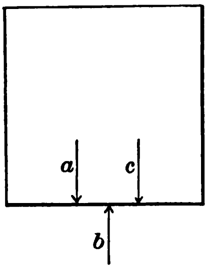

FIG. 34

The air in a schoolroom, 30 × 20 × 10 feet, weighs about as much as two barrels of flour, and the air in a lecture room, 100 × 50 × 20 feet, weighs about 4 tons. This is an insignificant portion of the whole atmosphere, the volume of which we are unable to determine, but whose weight is readily found.

If we boil water in a test tube, Fig. 35, for some time we may drive out all the air and fill the tube with steam. If now we fit a rubber stopper airtight into the mouth of this tube and allow the steam to cool, it will condense to a few drops of water and leave the tube above the water empty. The pressure of the atmosphere upon this stopper is 15


FIG. 35

pounds per square inch, which is the same as the pressure of a column of water 34 feet high. We could balance the pressure of the atmosphere against water pressure if we could take a tube a little more than 34 feet long, boil all the air out of it, and hold the open mouth under water while it cools. The atmosphere outside would press water in and up the tube until the vertical height of *a* above *b*, Fig. 36, was 34 feet. Since a tube 34 feet long would be inconvenient, we use mercury which is 13.6 times as heavy as water, and hence the column *ab* needs to be only 30 inches to represent the same pressure. Such an instrument is very much used and is called a barometer (pressure meter). By observing it from day to day, we learn that there is a variation of about half a pound per square inch in the pressure of the air, but the average pressure is about 15 pounds per square inch, or 30 inches of mercury. The enormous weight of the air is impressed upon us when we consider what it can do in motion. Air rushing against buildings sometimes knocks them over, breaks down great trees, piles up great sand dunes, great snow banks, great waves, strikes against the sails of ships and drives them rapidly, or even strips them of sails, rigging, and masts.

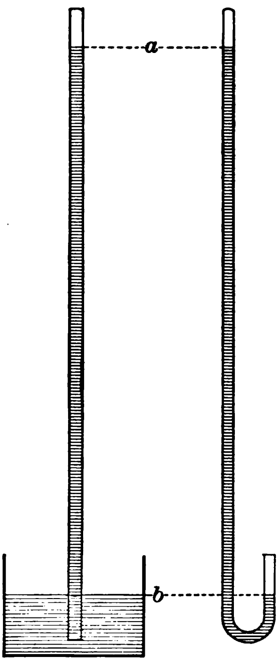

FIG. 36

A column of air whose height is that of the atmosphere and whose base is one square foot, weighs something over

one ton, and a column whose base is as large as the floor of the lecture room mentioned above weighs between 5000 and 6000 tons. Fortunately pressure in fluids is transmitted without loss and is the same in all directions. Hence the air presses in through keyholes, and cracks in windows and doors, at the rate of 15 pounds per square inch, so that the upward pressure under the floor is equal to the downward pressure above the floor, and thus the floor is not crushed by atmospheric pressure.

Our own bodies are not crushed by the many tons of atmospheric pressure upon them, because the air penetrates into every cavity of the body and balances this external pressure. If, however, we *suddenly* go up in a balloon, where there is less atmosphere above us and therefore less external pressure, the gases which are pent up in the cavities of the body expand and give distress. This is particularly true of the air in the inner chamber of the ear. If we climb slowly to the upper regions of the atmosphere, as in the ascent of a mountain, these pent-up gases have time to escape.

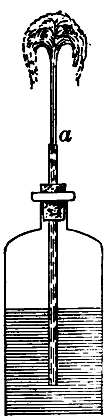

FIG. 37

The compressibility and elasticity of the air were mentioned on page 14. They are illustrated by the coiled spring, Fig. 1, *a*, which has an upward thrust, or tension, equal to the weight upon it. The elasticity of the air is illustrated by the apparatus represented in Fig. 37. If one applies his mouth to the end *a* of the tube, he may force more air into the bottle and compress it in the upper part of the bottle over the water. He will see this air pass in bubbles through the water. When the mouth is removed from *a* the air because of its elasticity will push the water out in a fountain.

Thus it is with the so-called siphon bottles of mineral water. Carbon dioxide gas is forced in under great pressure, and this reacts to force the water out when the valve is opened. The "soda-water" fountain has a steel cylinder charged with water and compressed carbon dioxide gas. It is this compressed gas which forces out the water when the valve is opened. Likewise in fire extinguishers compressed carbon dioxide gas drives out the stream of liquid. It is the elasticity of compressed air in the chamber of the force pump which keeps the stream of water flowing steadily between the strokes of the piston (see Fig. 38).

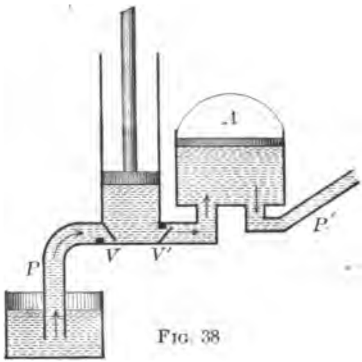

FIG. 38

If it were not for this device enabling the fire engine to throw a steady stream of water, the firemen could never aim the stream at any particular part of the building desired. Compressed gas not only discharges "air" guns, but all guns, great and small.

All explosions and all rock blasting illustrate the tension of compressed gases. In most cases to be sure the gases are not compressed by pumps, but are set free suddenly by chemical action in some material like gunpowder. Bread is raised by the elastic force of carbon dioxide gas set free by chemical action within the dough. The Manhattan Elevated Railroad trains blow their whistles by means of compressed air.

The so-called "hydraulic" elevators might quite as appropriately be called compressed air elevators. Figure 39

represents the principle upon which they work. A pump not represented in the figure pumps water through the tube *a* into a chamber *b* and compresses air in its upper part. When the valve *c* is opened in a certain way, water is forced out by this compressed air and passes into the cylinder and pushes up the piston *d*, which carries up the platform *e* with its load. When it is desired to bring the platform down again, the valve *c* is turned in such a way that the water from *b* is shut off and that from *d* may pass out through the pipe *f* back into the tank from which it will be again pumped up through *a* into *b*. This is the simplest form of hydraulic elevator and is much used to raise loads from the cellar to the sidewalk. This type of elevator has recently been perfected and is used in some of the largest buildings as a passenger elevator. Another type of elevator is equipped with pulleys so as to gain speed. The mechanism is suggested in Fig. 40. *b* is the compressed-air chamber as before. The water is forced from it to the upper end of the cylinder, and in

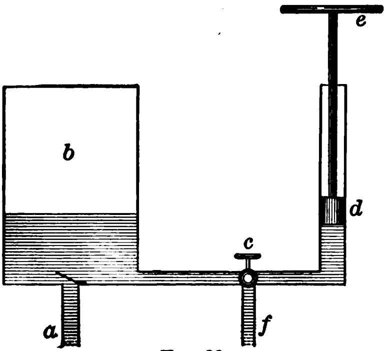

FIG. 39

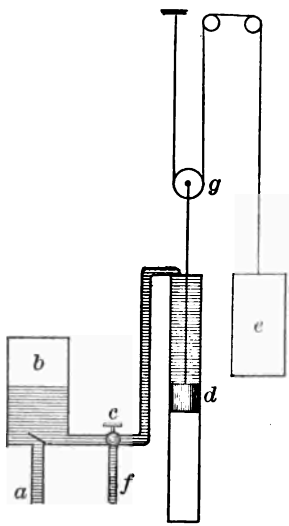

FIG. 40

this case pushes the piston *d* down. This pulls the pulley *g* down and the elevator car *e* up.

Compressed air by its expansion can be used to run machinery as steam does by its expansion. A few years ago a compressed-air motor was used to run a street car in New York city. Hot-air engines, so much used for pumping water, operate by the expansion of air due to heat.

The operation of the air pump in exhausting the air from a vessel is dependent upon the tendency of gases to expand indefinitely when the pressure is removed from them. Suppose we connect by means of rubber tubing the nipple *a*, Fig. 41, with a bottle from which we wish to exhaust the air. We then lift the piston *b*. The air from without, attempting to enter, closes the valve *c*. The air in the bottle expands, and a portion of it passes into the cylinder under *b*. When now the piston descends the air underneath it pushes the valve *d* shut and the valve *c* open and passes out. The operation is then repeated many times, but no pump can take all the air out of the bottle, because at length its elasticity becomes too slight to push the valve *d* open, and also because it at last does not supply air enough to the cylinder with which piston *b* may push open the valve *c* against the atmospheric pressure. Air and all gases tend to expand indefinitely, but this outward tension grows rapidly less as the distance between the molecules grows greater. Gases expand or contract until the tension is equal to the pressure upon them, and hence all the rooms in a building and all the cavities in the body, which are in communication with

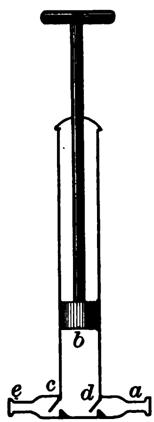

FIG. 41

the atmosphere, have a tension of about 15 pounds per square inch. The inner chamber of the ear has a communication with the outside air by means of a fleshly tube, called the *eustachian tube*, which opens into the throat.

The instrument represented in Fig. 41 may also be used for condensing air or other gases into a vessel. Suppose the bottle be connected with the nipple *e*. At first the inward pressure of the air upon the valve *d* is 15 pounds per square inch, but this is balanced by the tension of the air in the cylinder and in the bottle. When now we pull up the piston *b*, the air in the cylinder expands to fill the larger space and its tension grows proportionately less. The tension of the air in the bottle closes the valve *c*, and the air from without pushes in through *d* until the cylinder contains air enough to make its tension the same as the pressure from without. When now we push *b* down, *d* is pushed shut and *c* is pushed open and the air in the cylinder is pushed into the bottle. This may be repeated so long as the bottle and its fittings will stand the increased tension, or so long as we can exert pressure enough upon *b* to crowd more air into the bottle.

If the tension of the air in the bottle at the beginning of the experiment is 15 pounds per square inch, we find that when twice as much air has been forced in, its tension becomes 30 pounds per square inch, and when three times as much is forced in the tension is 45 pounds per square inch, etc. This relationship was discovered about two and a half centuries ago by Robert Boyle.

The so-called "siphon bottles" of carbonic acid water have carbon dioxide gas forced into them under a pressure of 9 or 10 atmospheres, say 140 pounds per square inch, hence the tension upon the sides of the bottle is very great, and accordingly the glass is made very thick.

The "chemical" fire extinguishers depend upon the tension of pent-up gas to drive out the liquid which they contain.

Suppose, as represented in Fig. 42, we connect a long tube with the pump already described and let the tube dip into some water. We may then use this instrument as a water pump. At the outset the pump and the tube *f* are full of air having a tension of 15 pounds per square inch. When now we lift the piston *b*, the tension of the air in *g* is reduced. Atmospheric pressure pushes the valve *c* shut on one side and on the other side pushes some water up the tube *f*. When the piston descends, it pushes the air in *g* against both valves *d* and *c*. The former closes and the latter opens, allowing it to escape. The water is held part way up the tube *f* by the pressure of air behind it. When *b* is lifted again, the water may be pushed into *g*, and when *b* descends again it is pushed out through *c* in a stream. The word *suction* appears to have no proper place here. Since it is the lifting upon the piston followed by the pushing of the atmosphere to get into the cylinder *g* through the tube *f* which causes the water to rise, it is more natural to call this a lifting pump, or better, simply a pump.

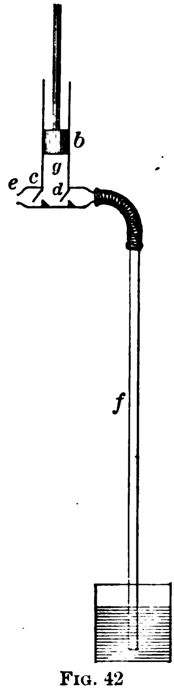

FIG. 42

The tube *f* cannot be more than 34 feet in vertical length, since the atmospheric pressure will not push water more than 34 feet high. And since no pump will reduce the tension of the air in *g* to zero, the pressure of the

atmosphere cannot in practice be utilized for raising water to even that height. If, then, we need to pump water higher than the atmosphere will push it, we connect a second tube to the nipple *e* and carry it to any desired height. On the ascending stroke of the piston, the atmosphere pushes the water as high as *g*, and on its descending stroke the piston pushes it up the second tube. This is called a force pump, but for no very good reason.

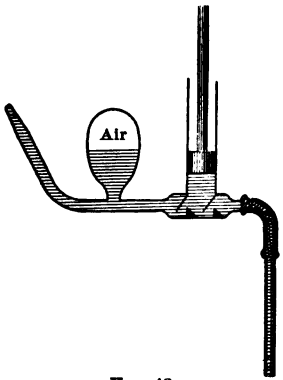

FIG. 43

It will be noticed that water passes out through the valve *c* only when the piston descends. It is sometimes necessary to have a pump deliver a continuous stream of water, as in the case of a fire engine, in which case the tension of compressed air is utilized to force on the stream while the piston is rising. The air chamber is introduced in many different ways, but may be connected as shown in Fig. 43 (see also Fig. 38, p. 57).

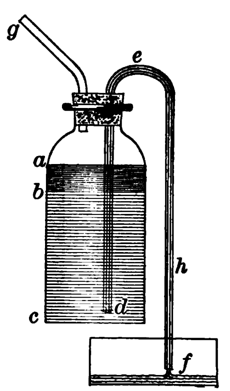

FIG. 44

Figure 44 represents a bottle of milk which has stood until the cream *ab* has risen to the top. Suppose we desire to separate the cream from the milk. It will be found to be very difficult to do so by pouring it off. We may bore a hole in the bottle at *c* and keep it corked with a small rubber stopper and draw out the "skimmed" milk from under the cream in that way. But it is not always convenient to use the same

bottle. The figure presents an instrument which will enable us to separate the cream from the milk in any bottle. The bent-glass tube *def* is called a siphon (the so-called siphon bottles are misnamed, as will appear shortly). It is important that the arm *ef* of this siphon should be longer than the arm *ed*. A second tube *g* passes through the stopper. A person removes the cap from any milk bottle and inserts this stopper with its tubes. Then placing her mouth at *g* forces a little air into the bottle. The increased pressure drives milk up the tube *de* and over into the second vessel at *f*. As soon as it begins to flow into the second vessel, the person removes her mouth from *g* and the milk continues to flow. The atmosphere presses inward equally at *g* and at *f*. The pressure of the column of milk *ef*, however, is greater than that of *ed*. And it is this excess of weight which operates the siphon. Any bent tube used in this way is called a siphon. The tube *g* is not a part of the siphon. It is merely a convenience in starting the flow of the liquid.

City Water System

It is a matter of common experience that water flows more rapidly from a faucet at some times than at others. It may happen that so much water is being drawn from faucets on the floors below that scarcely any water will flow from faucets upon the floors above.

In the water system of a great city, it is a well-nigh impossible task to furnish sufficient pressure to supply the demand at all faucets.

Manhattan Island is divided into three districts for the distribution of water: one is supplied from the Central Park reservoir, which is 115 feet above the sea; the second

is supplied from the reservoir at High Bridge, elevation 206 feet above the sea; and the third is supplied from the tower at High Bridge, 325 feet above the sea. In addition to the force of gravity, steam pumps are constantly at work to increase the water pressure; but since about 300,000,000 gallons of water a day are used in the Boroughs of Manhattan and the Bronx alone, it is impossible to rush the water along fast enough to supply the demand and maintain any considerable pressure. Indeed, very many of the buildings on Manhattan Island require extra pumps to force water from the street mains into their own private tanks.

Smaller cities and towns sometimes depend upon a mountain lake to give sufficient pressure, or this supplemented by a very large and tall tank called a "standpipe," which is often higher than the source of water supply and is used not so much for storage as for increasing pressure. Pumps are constantly worked to force water up into this standpipe, and are adjusted so as to keep the supply just equal to the demand. Very many towns depend upon a source of water such as lakes or wells at a lower level than the town itself, and their entire dependence is upon the pumps.

The largest water main in Manhattan is 4 feet in diameter. In a large public building where the daily consumption of water is 25,000 gallons, the water pipe which enters the building may be 4 inches or more in diameter. In a private dwelling house the main water pipe is frequently 1 inch in diameter.

Since the consumption of water is less at night than in the daytime, the pressure is greater at night. In buildings which have no pumps and tanks to maintain a constant pressure, it may happen that water will flow from faucets on upper floors only at night. Water is among

the most abundant things in the world, but the expense of bringing it to the city and the consumer makes it cost, in New York city, $1 a thousand cubic feet which is equal to 7500 gallons.

In order that the charge may be just, a water meter is, or should be, placed in each building. These meters are so simple that they seldom get out of order, and when they are out of order they generally, contrary to popular opinion, favor the consumer.

A stopcock is placed in the water pipe where it first enters the building in order that the flow may be readily shut off in case of any leak about the house. It is well that every one in the house should know where this stopcock is, since great damage is often caused by leaks before a plumber can be secured. This stopcock is what is called a "three-way cock." By means of it the water may not only be shut off from the house system, but also drained out of the pipes. Figure 45, *a* shows such a cock set so as to deliver water up into the house system, and *b* shows it set so as to both stop the flow from the street and drain the water out of the pipes in the house. When the cock is turned to drain the pipes the highest faucet in the house should be opened to let the air into the pipes, otherwise all the water will not run out of them. It is particularly necessary to drain the pipes if the house is to be shut up for a period in winter, lest the water freeze in the pipes and burst them. It is wise also to do it if the house is to be shut up for the summer, so that damage may not occur from leaks.

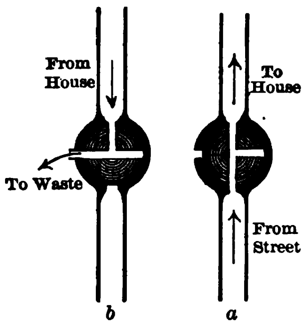

FIG. 45

There is also another stopcock outside the house where the house main joins the street main. This is the stopcock which may be closed by the Water Department when the householder neglects to pay his water tax.

Still farther back in the system there are stopcocks or valves in the street mains which, upon due notice to the householders, may be closed for repairs upon the street mains. In which case the householders are fortunate if they have storage tanks on the roof to supply their needs until the repairs are completed. If not, their only recourse is to draw just before the water is shut off as many vessels full as shall tide them over.

For purposes of internal repairs it is well that there should be several stopcocks, other than faucets, about the house so that water may be shut off of one portion of the system while other portions may still be in use. Such a stopcock is generally placed in the pipe which leads to the hot-water tank, see *o*, Fig. 46. If this is closed, either the fire which heats the water must be put out or some hot-water faucet must be opened to allow the expansion of the water by heat. Fig. 46 shows the basement and two stories of a house in elevation in which one branch of the cold-water pipe may be traced to the cold-water faucet *b* at the kitchen sink; another branch goes to the cold-water faucet *c* at the wash-bowl in the bathroom, another goes to the cold-water faucet *d* in the bath tub, and another goes to the stop-cock *e* in the small tank over the seat. This stopcock is of the variety called a "ballcock," or floating stopcock. A hollow metal ball *f* 5 or 6 inches in diameter floats upon the water in the tank and closes the stopcock *e* when the tank is full, but by its weight opens this stopcock when the water flows out of the tank.

Another branch of the cold-water pipe not represented in the figure goes to the "set tubs" in kitchen or laundry for washing clothes.

Another branch of the cold-water pipes carries water to the hot-water tank *j*. From this it is led into a small

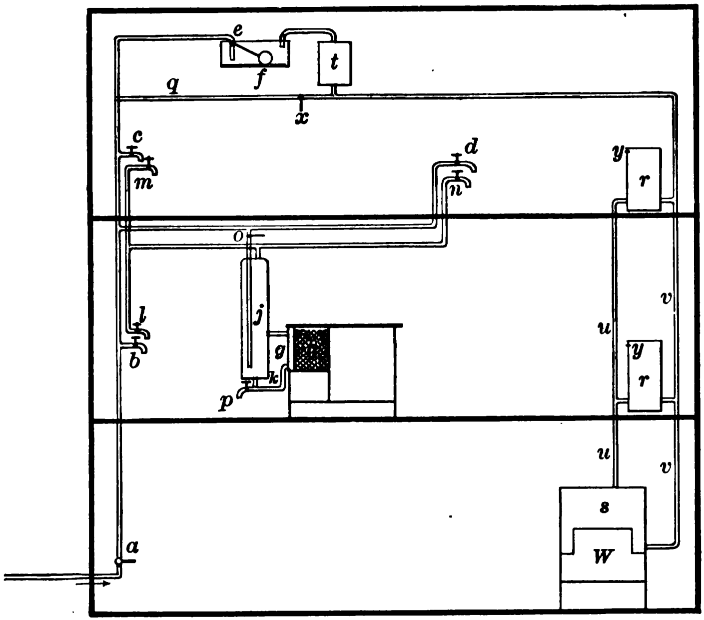

FIG. 46

tank *g* which furnishes one wall of the fire box *h* of the stove. The tank *g* bears the name "water front." From this it is pushed on by the pressure behind into the storage tank *j* again. If it remains there long enough to get somewhat cooled, it contracts and becomes heavier than the water in *g*, and presses its way into the water front again by way of the pipe *k*, forcing the hot water from *g*

into *j*. The heat of the stove keeps the water constantly moving around this circuit, and thus the water in *j* is heated continuously so long as there is a fire in the range. From this tank *j* pipes run to the various hot-water faucets *l*, *m*, and *n*, etc. When water is drawn from any of these, more enters the hot-water system through the stopcock *o* to supply its place. *p* is a faucet to draw off water from the bottom of the hot-water tank, where dirt often collects and gives a disagreeable smell to the hot water unless occasionally cleaned out.

It is essential that the pipes should pitch in such a manner that all water may be drained out of them through faucets and the three-way cock *a*. Any portion of pipe which was run so that water could not be drained out of it would be called a pocket. This is never to be found in good plumbing.

Water has a very great capacity for storing heat, as will be brought out in the chapter on Heat. It is therefore much used for distributing heat about a house. *q* in Fig. 46 represents a branch of the cold-water system which supplies water to the heating system. This water fills the radiators *r* and the hot-water tank *s* at the furnace in the cellar. When fire is started in the furnace *W* it heats the water in *s*, which expands and is pushed up the feed pipe *u* into the radiators *r* by the colder and heavier water which presses down the return pipe *v*. Thus the heat of the furnace is constantly distributed to the radiators, and they return the water as it cools for fresh supplies of heat. The system being already full, as the water expands by heat it rises in the "expansion" tank *t*, or may overflow a little into the tank at *f*. The stopcock *x* needs to be opened, say once a month, to let a little water into the system to supply what has been lost.

Air will occasionally be found in the upper part of the radiators. This is let out at the small stopcocks, called "pet valves," *y*.

If the fire in the furnace gets too hot it may boil the water and drive much of it out of the system through the expansion tank *t*. At length, the rumbling sound and the steam pouring out into the bathroom warns one that the fire in the furnace must be checked. A house should have radiating surface enough so that it is never necessary to raise the temperature of the water in the heating system above, say, 140°, to keep the rooms at about 68°.

A city water system necessitates also a system of waste pipes, and these pipes must be of greater capacity than the water-supply pipes, since they must carry off not only all the water which is distributed by the supply pipes, but also the vast quantity which falls as rain, or results from the melting of snow and ice. The sewers, therefore, have large openings at the corners of streets to receive the water that flows along by the curbstones. At frequent intervals along the curbstone there are large outlets, called hydrants, from the water system, to supply water for extinguishing fires and washing streets. This water finds its way very directly into the sewers.

The water flows in all the sewers by the force of gravity alone, and the grade is frequently not more than $\frac{1}{4}$ of an inch to the foot, or about 2 per cent. These sewers on Manhattan Island empty their water all along the shores of the Hudson, Harlem, and East rivers.

Each building has a separate connection with the sewer running in the street in front of it.

Figure 47 shows the main features of the waste-pipe system of a house. Each sink, washbowl, water-closet seat, bath tub, or "set tub" must have a trap in its waste

pipe. Those shown at *a*, *b*, *c*, and *d*, Fig. 47, are called S traps, and are about the only ones in common use in private houses. An S trap is shown more in detail in Fig. 48. *a* is the sink, and the bend in the waste pipe from *b* to *e* is called the trap. A trap serves several pur-

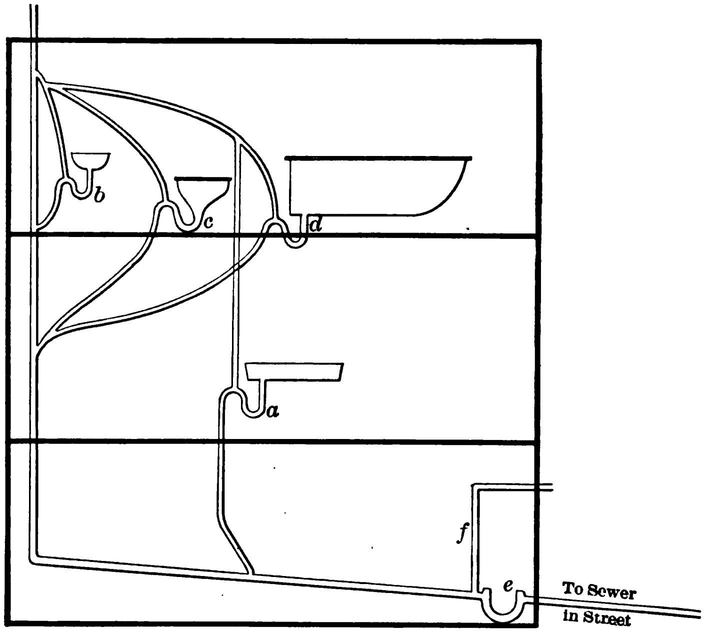

FIG. 47

poses. Water stands continually in the bend of the trap *bdc*, and prevents sewer gas from coming back into the house. This is its chief purpose, but it also serves to arrest substances that might clog the waste pipe. A cap is provided at *d* which facilitates the cleaning out of this trap. At the crown of the trap above *c*, a branch pipe starts, which goes to the outside atmosphere above the

roof of the house. This is sometimes called a ventilating pipe, and sometimes a "back-air" pipe. It provides a means of escape for gases which may form in the waste pipes, and which, by reason of unusual pressure, would sometimes bubble through the water in the trap. It is called a "back-air" pipe, because it prevents the trap from emptying itself by the process of siphoning. Water running down the long arm *e* might siphon all the water out of the portion *bdc*, particularly in a small waste pipe, if it were not that air could freely enter by way of the back-air pipe.

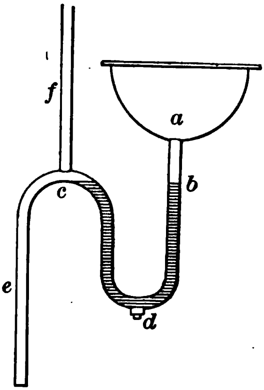

FIG. 48

A U trap is inserted at the point *e* (Fig. 47), where the main waste pipe leaves the house on the way to the street sewer. A vent pipe *f* rises from the house side of this trap and passes through the basement wall to the outside air.

It is a very simple thing to unscrew a water faucet and put on a new washer. Washers may be obtained at any hardware store, and those who acquire the habit of keeping a few on hand and replacing the worn-out ones when faucets begin to leak, save themselves much annoyance and a considerable expense in plumbers' bills and water tax, — at least, one family has been known to reduce the water tax one-half by adopting this precaution. It is estimated that 45,000,000 gallons of water per day are lost through leaky fixtures on Manhattan Island. Since less than 3,000,000 people (including transients) in Manhattan and the Bronx are supplied with 300,000,000 gal-

lons of water per day, it follows that 100 gallons of Croton water each day is expended for each inhabitant. If this portion of Greater New York continues to grow five years longer at the rate it is now growing, all the rain which falls on the Croton watershed will not supply 100 gallons a day to each individual.

City Gas System

Illuminating gas is made from many different substances. In New York city at the present time a large amount of the gas is made from soft coal. The coal is heated in air-tight retorts. This breaks it into solid, liquid, and gaseous products. The porous black solid is called coke. The liquids are a mixture of tar, ammonia, etc., and the gaseous product is a mixture of several gases. This mixture of gases and vapors is led in pipes through cooling chambers, where much of the vapor of liquids is condensed and drained out. The gas is then washed of the remaining liquid products by being violently shaken up with water. This process, however, saturates the gas with water vapor, which gives trouble in several ways. In cold weather the water vapor condenses and gathers in pockets of the gas pipe, and reduces the flow of gas, or may, in some cases, stop it altogether. In extremely cold weather it freezes in exposed places and bursts the pipe. When people speak of the gas freezing, the freezing of water in the system is referred to. This is a source of peril to those who leave gas burning at night when the family is asleep. Suppose the freezing takes place in a portion of the gas pipe in the cellar, and shuts off the flow of gas and extinguishes a flame left burning in a bedroom where some one is sleeping. Suppose, then, very early in the morning the fireman quickens the fire in the furnace, which is in the

cellar, and the ice in the pipe thaws sufficiently to let gas pass on into the bedroom. The person asleep is liable to die before regaining consciousness.

The gas meter records cubic feet. The volume of gas increases as the temperature rises and as the pressure grows less. The pressure is kept pretty constant. It must, of course, be a little more than that of the air, otherwise the gas would not push its way out through an open stopcock against atmospheric pressure. The excess of gas pressure over that of the air is so slight that it can scarcely be felt if one holds back the flow by pressing his thumb over a very small outlet. It is often about 2 ounces per square inch, or enough to hold up a water column $3\frac{1}{2}$ inches. As in the case of the water system, so with the gas, the pressure varies much according to the amount consumed. Thus we should expect the pressure to be reduced in the early evening when people begin to light up. The gas company, however, undertakes to regulate the flow into the mains so as to keep the pressure as constant as possible. The pressure in different parts of the system may vary much on account of varying sizes of pipes. It is found that the pressure may vary as much as from 1 to 5 inches of water in the same building and at the same time. A simple way to determine the gas pressure is to connect a glass tube by means of a rubber tube to a gas outlet and dip it into a bottle of water, Fig. 49. The glass tube may have a scale of inches scratched upon it with a file. Pressure

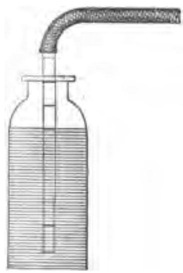

FIG. 49

in liquids is the same in all directions, and if the water in the tube is depressed, say, 4 inches below the level of

the water in the bottle, the pressure of the gas is sufficient to hold up a column of water 4 inches high.

The variations of gas pressure mentioned above, together with variations in atmospheric pressure, may cause the volume of a given quantity of gas to vary as much as 5 per cent. That is, a cubic foot of gas as measured by the meter may be 5 per cent more at one time than at another, due to changes of pressure. But heat also expands gas, and the difference in volume of gas as registered by meters put in the kitchen or in the cellar might be as much as 10 per cent.

It is a very simple thing to renew gas tips, and it is very desirable to do so occasionally for the sake of efficiency and economy in lighting. The gas tips need to be selected with reference to the pressure. If a gas jet "sings," the pressure is too great for that tip. The matter may be remedied either by substituting a tip that will allow more gas to pass, or by partially closing the stopcock to reduce pressure. The so-called lava tips, which may be procured at any hardware store, have rings about them to tell how much gas they will discharge, — one ring for each cubic foot per hour up to four, then a broad ring for each 5 feet.

The Atmosphere of a Great City

Manhattan Island is blessed in that nearly all winds which reach it must first come across water. Thus its winds are not only cooled in summer and warmed in winter, but they are fairly clean, and they sweep the dust out of the streets into the rivers. If these winds bring rain, it washes the streets in a most thorough manner, and the water readily finds its way to the rivers on either side.

New York city has such a dense population, all vitiating the air by breathing it; so many animals doing the same; so many fires doing the same; so much fermentation, disease, and decay, and so little vegetation to counteract the evil, that its population would perish if it did not have constant currents of fresh air coming in from outside. The currents of air are chiefly due to the fact that the atmospheric pressure is variable, and there is motion from a place of high pressure to one of low pressure. It is not very pleasant to think of a city throwing all its wastes into the same lake from which it gets its drinking water, even though the lake be very large. This is what all the world must do with reference to the air it breathes. The inhabitants of Greater New York give out about 60,000,000 breaths per minute, and pass through their lungs about 1,400,000,000 cubic feet of air per day. No one wants to take back again his own breath, much less that of another person. This large volume of air, containing excretions from the lungs, is poured forth into the same atmosphere which must be the source of respiration for us all. Fortunately for New York people, it is blown away into the country, where it supplies the chief source of nutriment for the plant world, which restores the air to its original state of purity.

HEAT

THE NATURE AND SOURCES OF HEAT

EXPERIMENTS

Sources. The Sun. — With convex lens (reading or burning glass) focus sun's rays on piece of thin paper. What effect is produced on the paper?

Friction. — Rub palms of hands briskly together, or rub hand on desk, or metal button on coat sleeve. What effect in each case?

Percussion. — Hammer piece of lead or iron, and quickly note temperature with hand.

Compression. — Compress air violently in bicycle pump. What effect has compression on temperature of air?

Chemical Combination. — Pour water slowly upon quicklime. Is there any change in temperature?

Combustion. — Observe and account for production of heat in ordinary gas, candle, or Bunsen flame.

Electricity. — Observe incandescent bulb, or connect two or three cells in series and pass current through short and very fine wire. What effect on temperature of wire?

Temperature. — Fill three cups, A with hot water, B with tepid water, and C with cold water. Place, for a few seconds, one hand in A and the other in C; then plunge both hands into B. Does temperature of water in B seem alike to both hands? Is the body a reliable indicator of temperature? Repeat, using two thermometers instead of hands. Do the thermometers read alike when they are in B? Place thermometer, graduated at least to boiling point, in cracked ice; then in boiling water. Note the reading in each case.

The sensation of heat is believed to be due to molecules striking against the skin. Substances whose molecules beat most rapidly upon one's skin are considered most heated. Anything which will agitate the molecules of a substance heats it. As the motion of the molecules of any substance becomes more vigorous, they push each other farther apart, and hence the substance expands while

heating. This is the way changes of temperature are recognized. Consider what happens according to this theory when a thermometer is plunged into hot water. The molecules of water beat against the molecules of glass, and they in turn beat against the molecules of mercury. This causes both the glass and the mercury to expand. The height of the mercury column is a measure of the amount of molecular motion in the mercury, which we call heat. But the most difficult thing to understand, according to this theory, is the fact that hot bodies may stir molecular motion in other bodies without the intervention of other molecules. Thus the sun whose molecules are in violent motion causes molecular motions in things upon the earth without there being molecules in the intervening space between earth and sun. The more one looks into this matter the more convinced he becomes that this is the fact, but we shall not attempt to explain it at present.

The sun warms everything upon which it shines by creating greater motion among its molecules. Things rubbed together get warm by reason of the increased molecular motion. Thus heat is produced by friction. Hammering, or jarring, or shaking a body increases the motion among its molecules. This is heat. Compressing a body shortens the paths in which its molecules move, and causes collisions to occur more rapidly. Chemical action increases molecular motion. Combustion is the most familiar example of this. An electric current when forcing its way through a conductor that resists its passage causes molecular motions, or heat, in the conductor. Things give us the sensation of heat when they are warmer than we are and effect an increase in the motion of our molecules. Things appear cold to us when we are imparting molecular motion to them, which of necessity decreases the motion of our

molecules. While our vital organs are kept continually at the same temperature, about 98°, the skin, where is located the sense of temperature, has variable heat according to its surroundings. If one passes from a superheated room to one of 68°, he considers it chilly. If, on the other hand, one passes from the winter's cold into the room at 68°, he considers it warm, or perhaps too hot. Since our temperature sense deceives us, we come to rely upon the thermometer for correct tests of temperature. The scale of degrees is marked upon the stem of the thermometer. Various countries have adopted different scales for measuring heat. Upon the scale in household use in America the proper temperature of a living room in winter is 68°. The temperature of one's blood is 98°. The temperature of melting ice is 32°. This is also called the freezing temperature, although that is more variable. The temperature of boiling water is about 212°, with a variation of several degrees. It may be useful to remember these figures.

EFFECTS OF HEAT

Experiments

Effects of Heat on Solids. — Heat metal rod. Note effect. Allow rod to cool, and again note effect. Heat compound bar. Which metal expands more?

Effects of Heat on Liquids. — Arrange small flask with rubber stopper and glass tube passing into it. Completely fill with water. Heat over Bunsen burner, and observe behavior of water. What molecular change has taken place in liquid?

Effects of Heat on Gases. — Place hand on bulb of air thermometer, the tube of which dips beneath the water in a tumbler. Note and explain results. Allow to cool, and explain behavior of water.

Change of State. — Place a small lump of ice in test tube. Heat carefully until nothing remains in tube. Observe changes of state.

Ebullition and Liquefaction. — Heat flask half full of cold water to boiling. Can you see steam in flask? What do you see at mouth of flask? What becomes of this? Place cold glass plate or tumbler near mouth of flask. Note and explain results. Account for fogs, clouds, and rain.

Fusion and Solidification. — Completely fill a tumbler with melted paraffin. Allow to cool and solidify. Does it shrink or expand? Does water shrink or expand on solidification?

Evaporation. — Place a few drops of ether on back of hand. What becomes of the ether? What effect is produced on hand?

One can scarcely escape being familiar with the fact that heat expands substances. A very interesting illustration of it may sometimes occur in connection with the hot-water system. In a certain house a hot-water pipe ran 20 feet in a straight line resting across the timbers of the second floor. In winter weather the temperature of the water in that portion of the pipe might suddenly change as much as 170°. For if no water were drawn in the washbowl upstairs for several hours, the water in the pipe would get as cold as that in the cold-water pipe; and

when the faucet at the farther end of this pipe was opened, the hottest water of the kitchen tank would suddenly rush through the pipe. The result was that the pipe expanded with heat and lengthened, and in pushing itself across the timbers it jarred the whole house. Some buildings in New York city have many miles of hot water and steam pipes, and allowance must always be made for contraction and expansion due to changes of temperature. The natural way to provide for this is by inserting angles in the pipe. In most buildings enough of these are provided for other purposes to cover this requirement also.

A visit to a wheelwright's to see a tire of steel 4 inches broad and 1 inch thick put upon a wagon wheel is instructive. This tire must bind the wheel very tightly to prevent its working off, and it must be stretched in order to get it on. It would require a tremendous force to stretch a band of steel 4 inches broad and 1 inch thick. Yet the heat from a little burning charcoal does it quietly and quickly. No wagon wheel can withstand the force with which this tire contracts upon cooling, and hence it is important that it should be made so that it will be just the right size when it is cold to bind the wheel very tightly, but not to "dish" it out of shape. "Setting" a wagon tire, as the process is called, suggests that very many pieces of metal apparatus are put together in this manner. When one circular piece is expanded by heat and then put upon another and allowed to contract in its place to make a tight fit, we say it is "shrunk" on. It is interesting to look over pieces of apparatus and try to decide what portions were cast whole and where joints occur; also to decide what joints were brazed together, what were shrunk together, and what were screwed to-

gether. Only the latter can be taken apart. It is very common for persons to spoil nice pieces of apparatus by trying to take them apart in the wrong places.

All solids do not expand and contract alike for equal changes of temperature. For example, brass expands a little more than iron for each degree rise in temperature. Many applications are made of this principle. In the best equipped school buildings the heating is automatically controlled by a device placed in each schoolroom called a thermostat. The essential part of the thermostat consists of a strip of iron *a*, Fig. 50, soldered to a strip of brass *b*. When the room gets too warm, *b* expands more than *a*, and the strips curve toward *a*, as shown in the figure. They are so arranged that in this position they shut off steam from the room. When the room gets too cold, the strips curve toward *b*, and turn on steam in the heating apparatus of that room. It is not necessary to give further details of the apparatus. But in view of the fact that reference has been made in a former chapter to the uses of compressed air, it is interesting to note that the strips of iron and brass do not open and close the steam valve directly, but operate by means of compressed air. Each steam valve is kept closed by compressed air. The thermostat, when the temperature falls, shuts off the compressed air and a spring opens the steam valve. As the temperature rises, the thermostat turns on the compressed air, which closes the steam valve again. This, at least, is one form of thermostat, and it is sensitive to a degree or two change of temperature.

FIG. 50

The thermometer often used in railway cars operates upon the same principle. A strip of iron coiled like a

clock spring has a coiled strip of brass soldered parallel to it, Fig. 51. One end of this coil is fastened to the metal case and the other end is free to move. The unequal expansion of the metals when warmed causes them to uncoil slightly and this movement is communicated by cog wheels or other device to an axle carrying an index which moves about the dial pointing to degree marks. The gearing between the coiled spring and the pointer may be made to produce large motion of the index for very small movement of the coil, and thus degrees or fractions of degrees, as marked upon the dial, may be large enough to read at a distance.

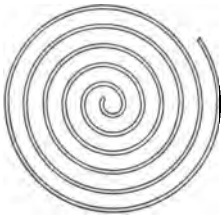

FIG. 51

The ordinary thermometer, made of mercury or alcohol, illustrates the fact that heat expands liquids and that this expansion may be used to measure temperature. A thermometer is usually made of a glass tube having an exceedingly small bore with a bulb at one end and the other end closed. Air is removed from the tube and mercury admitted before it is sealed up. Sometimes alcohol is substituted for mercury. It is important to use a liquid which will not freeze at ordinary temperatures, and it is important to make the tube long enough to permit the liquid to expand according to the temperature to which it is to be subjected. The thermometer used by physicians for determining the temperature of sick persons has a range of only a few degrees around 98° upon its scale, and hence it cannot be washed in hot water lest it should expand so as to burst its tube.

The expansion of liquids by heat is also illustrated by the "expansion tank" in the hot-water heating apparatus represented at *t*, in Fig. 46, p. 67. A glass-tube indicator,

upon the side of this tank, may be used as a thermometer to indicate roughly the state of the fire in the furnace. The hot-water boiler *s* is the bulb of this thermometer, the pipes are the thermometer tube, and the liquid used is water instead of mercury.

The expansion of solids and liquids by heat is trifling compared to the expansion of gases.

Consider what happens when a teakettle partly filled with water is heated upon the stove. The heat expands the iron of the kettle only *about one fifth* as much as it does the water in the kettle, and it expands the water in the kettle only *about one twentieth* as much as it does the air in the vessel. While, however, the water is changing to a gas, it expands to about 1700 times its original volume, and after it has assumed the gaseous state it expands at exactly the same rate as the air. Solids have different rates of expansion; and liquids have different rates of expansion, but all gases expand alike for each degree rise in temperature.

The engineer as soon as he lights his fire opens a valve for the escape of steam, or air before steam is produced. Laboratory students sometimes set up apparatus, in which heat will expand water, without providing any outlet.

The force with which heat expands water is the force which propels steamboats and railway trains, and drives most of the machinery of factories.

Whether a substance shall be solid, liquid, or gaseous appears to be only an incident of temperature. In the teakettle mentioned above we have at ordinary temperatures the iron, a solid; the water, a liquid; and the air, a gas. If we raise the temperature to 212°, and maintain it there for a considerable time, the water will become a gas, wholly invisible at or about 212°. If we raise the

temperature to a little above 2000°, the iron will become a liquid, and if we should subject this kettle to the heat of the sun, it would assume the gaseous state. On the other hand the kettle, water, and air may all be solidified. The earth was probably at one time wholly in the gaseous state and, if it takes the course of other worlds, it will in time be wholly solid. It would appear that heat causes the molecules to move farther apart and thus changes the state of a substance. Thus, in general, below 32° water is a solid, between 32° and 212° it is a liquid, and above 212° it is a gas.

A cubic foot of water expands to about 1700 cubic feet in passing to a gas. Does it contract in passing from the liquid to the solid state? If so, ice would sink in water and water would not burst vessels in freezing. We say that in solidifying it crystallizes, and the molecules require a greater space in which to arrange themselves to form crystals. After it has become a solid it expands and contracts with changes of temperature like other solids. Many other substances in crystallizing act in the same way. As, for example, type metal and such metals as take a good impression when cast in a mold. Those who "fry in deep fat" know that, in the act of melting, the solid portions of the fat do not float upon the liquid, showing that solid fat is more condensed than liquid fat, and hence heavier. Paraffin acts in the same manner, and hence cannot well be cast in molds in making candles.

No substance, in our experience, is entirely without heat — that is, without molecular motion, and as a result of this molecular motion most liquids and some solids throw off molecules from their surfaces to form gases or vapors. Thus water evaporates at all temperatures. Ice also evaporates, as is evident from the fact that clothes

dry when frozen on the line. Camphor evaporates and throws off molecules from projecting portions, so that an irregular piece slowly assumes spherical shape.

Water which has evaporated eventually condenses into minute drops to form clouds, fog, or mist. Sometimes these minute drops gather together into rain drops, and sometimes they are again dissipated. Evaporated water may also condense upon cold objects to form dew, or, if the objects are cold enough, frost.

LATENT HEAT

Experiments

Heat water in open flask and note temperature from time to time. Note temperature of boiling water and of steam formed. Is steam hotter than boiling water? Does temperature rise after boiling point is reached? What becomes of heat added to water before water boils? Of that added after boiling begins?

It is a singular fact that while a substance is changing its state, its temperature will not rise however much it may be heated. The expression *latent heat* is used with reference to this phenomenon wherein there is an apparent disappearance of heat. Ice out doors in very cold weather may be much below 32°. Indeed, it has about the same temperature as the other objects about it. When put in a warm place its temperature will rise to 32°, but no amount of heat can raise its temperature above 32° so long as it remains ice. Heating it simply hastens its change of state to a liquid. As water, its temperature will rise regularly with heating until it reaches 212°, but at that point its temperature ceases to rise, and subjecting it to never so great heat will not raise its temperature at all while in the liquid state, but will merely hasten its change to the gaseous state. Mercury changes from solid to liquid at 38° below zero, and from liquid to gas at 594° above zero. It can be used for thermometers, therefore, only between these limits of temperature. Butter and lard change from solid to liquid at 92°, 6° below the temperature of the human body. Sulphur changes from solid to liquid at 239°, and from liquid to gas at 833°. Tin melts at 446°. This is lower than the temperature which the stove oven sometimes reaches, and hence the tinware

of the kitchen, which is iron with a thin coating of tin on it, soon loses its cover of tin by melting when subjected to a temperature as high as 446°. Tinware is prevented from reaching that temperature, however, if it contains water or any other liquid whose boiling temperature is below 446°. The "double boiler" is a familiar illustration of the same principle. If we want to insure that a substance on the stove shall not be heated above 212°, we place the vessel which contains it in another vessel containing water. At 212° the water in the outer vessel will prevent any further rise in temperature by its rapid evaporation. This makes it necessary that one should guard against the outer vessel's getting out of water.

The ice box is a further illustration of the same principle. If we want to be sure that the temperature of a substance shall not rise above 32°, we surround it with ice. The ice prevents the temperature in its immediate neighborhood from rising above 32° by absorbing heat and rendering it latent and changing its own state to a liquid as a result.

Water and many other substances evaporate at all temperatures, and it is important to state that at whatever temperature evaporation goes on it renders heat latent. Hence evaporation always produces a fall in temperature. This is why alcohol, ether, benzine, gasolene, and all those liquids which are volatile feel cold to the hand and *are* cold, as shown by the thermometer, *when free to evaporate*. When kept in tightly stoppered bottles their temperature does not differ much from surrounding objects.

The evaporation of water under ordinary conditions may reduce the temperature in its immediate vicinity as much as 10°. Any influence which will hasten evaporation will produce a still further fall in temperature.

Hence water may be frozen by the evaporation of ether if fanned to hasten evaporation.

Any influence likewise which will hasten the liquefaction of a solid will produce cold by rendering heat latent. Ice under the influence of salt and certain other substances liquefies rapidly and does so much below 32°. This freezing mixture, as it is called, causes heat to disappear from everything in its immediate vicinity, and renders that heat latent within its own mass while it changes state. Indeed, these substances cannot change their state unless they can procure the necessary amount of heat from some source. The reason why snow lasts so long in the spring time, and ice lasts so long on a hot summer day, and liquid air keeps so long in an open pail, is that these substances are unable to get heat enough by conduction, convection, or radiation to enable them to change their state any quicker than they do.

PROPAGATION OF HEAT

Experiments

Conduction. — Fasten piece of cardboard with wax to one end of stout brass or copper wire. Heat wire about 3 inches from card. Note and explain behavior of card. Repeat, using glass rod of about same size. Which substance conducts heat better? Test with thermometer various objects (*e.g.* iron, wood, cloth) in room. Have all the same temperature? Now touch them with hand. Do they now seem to have same temperature? Explain.

Convection. — By means of wire sink piece of ice to bottom of long test tube nearly filled with water. With Bunsen flame heat upper part of water to boiling. From behavior of ice, what is your conclusion as to heat conductivity of water? Perform, omitting ice and holding lower end of test tube in hand while heating. Arrange lighted candle and lamp chimney supported on two small sticks. Hold ignited touch paper near top and then bottom of chimney. Observe and explain direction of air currents. Fill small thin glass flask with colored hot water; close with stopper containing two tubes, and lower to the bottom of glass jar of cold water. Repeat, inverting glass flask and holding in cold water near top.

Radiation. — Place hand under flame of Bunsen burner held horizontally. How is hand warmed? Remove labels from two similar baking-powder cans, and blacken outside of one can. Fill both with hot water of same temperature and insert thermometer in each. Which cools more rapidly?

Experience teaches us to handle hot objects with holders of paper or cloth. We regard these latter as non-conductors of heat. A burning match conducts no heat through its wood. Ice is packed in sawdust because that does not conduct heat. Thus ice may be kept from one winter to another. The human body is fortunately a poor conductor of heat, and hence the vital parts are not subject to sudden changes of temperature. We inclose the furnace with a wall of brick or other non-conducting material, so that scarcely any heat may be perceived out-

side of the walls within a few inches of the fire. We cover steam and hot-water and hot-air pipes with non-conducting material to prevent loss of heat in transit; but when these pipes reach the room where the heat is needed, we on the contrary use metal radiators and increase their exposed surfaces as much as possible to facilitate the propagation of the heat. When one touches good and poor conductors, both being of the same temperature and cooler than the hand, the former feels the cooler of the two because it conducts heat away from the hand the more readily. If, however, they are both of the same temperature and warmer than the hand, the former feels warmer because it gives heat more readily to the hand by conduction. In general, the metals are the best conductors, but no substance conducts heat very well. The blacksmith heats one end of an iron rod red-hot while holding the other not many inches away in his bare hand. And if the iron is drawn out into fine wire one may hold a piece in the hand while melting it in a flame *two inches* distant. Not only the iron but air also intervenes between the flame and the hand in this case, and thus we may know that the air is a poor conductor. Air spaces in the walls and partitions of a house and between double windows prevent the passage of heat either in or out. The same may be said of clothing, especially of loosely woven fabrics like flannel. For this reason fur is an exceedingly non-conducting covering. The living human body generates more heat than it can endure. Hence, if we cover ourselves with an excessive amount of non-conducting material, we may suffer with the heat in the coldest weather. We naturally speak of such coverings as "warm" clothing, although they have in themselves no unusual heat.

Fortunately for us and all living things heat cannot travel far by conduction, else how could anything live upon this thin shell of earth with volcanic heat so little way below the surface.

Heat, as we have learned, expands substances, and this fact enables us to readily heat liquids and gases whose molecules are free to move among themselves. If a dish containing burning alcohol be floated upon a vessel of water, Fig. 52, *a*, it will heat the surface of the water and expand it, and this hot water being lighter than the rest will continue to float upon the top. Water is such a poor conductor that the lower portions will not become heated at all. If, however, the dish of burning alcohol be placed beneath the vessel of water, as represented at *b*, it heats the lower portions of the water and expands them, and they being lighter are pushed to the top by the colder and heavier portions, which in turn are heated and pushed up by other portions until all are heated. This method of heating is called *convection*. Manifestly it can only apply to liquids and gases, and its operation in them depends upon the facts of expansion and buoyancy.

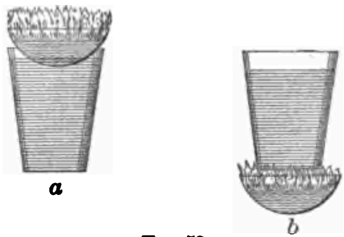

Fig. 52

We should naturally expect that variations of temperature would cause convection currents to exist continually in the ocean and all bodies of water, and in the atmosphere. This is true, and it in part explains winds and ocean currents.

Those persons who have waited for the kettle to boil know that even when a good fire is placed underneath a

vessel of water, convection is a provokingly slow method of propagating heat. Those also know the same thing who have waited on a cold winter morning for the house to get warmed by a hot-air furnace. Fortunately, there is a vastly more effective method of propagating heat than either convection or conduction. It is the method by which light is propagated. We have become accustomed to think of rays of light. They come in straight lines. They are not dependent upon intervening matter to bring them, although substances may obstruct their passage. Matter, such as bright metals, may reflect them; such as glass, may transmit them; or such as the earth, may absorb them. In the latter case the light rays are converted into heat, that is, molecular motion.

Rays which do not affect the eye come from all forms of matter, and travel independently of matter. When they are absorbed by other portions of matter, they increase the molecular motions which constitute heat. This is the chief method by which warm bodies transmit their heat to colder bodies and tend to make all things the same temperature. This is the method by which the sun warms the earth, and it is manifestly the method by which we get heat from a fire in the open fireplace. Certainly no heat reaches us in this case by conduction; certainly, also, in this case no heat reaches us by convection, since all currents of air are toward the fireplace and up the chimney. But the fire radiates heat, and may scorch our faces and clothing. It may do this when the air about us is very cold, since the air does not absorb heat as readily as we do. The earth is the great absorber of heat. If by means of a balloon we get as far away from the earth as possible, we then appreciate what it means to have it near us, absorbing the sun's rays and converting them into heat.

We then appreciate that the air has little to do with heating us, and we find that although bathed in air and sunlight, we get no heat except what we ourselves are able to absorb on the side of our bodies which is turned toward the sun. Then, too, we appreciate that in the matter of clothing we need that which is a good absorber of heat as well as a non-conductor of heat.

That there are invisible as well as visible rays, may be illustrated by sending an electric current through a coil of wire. A moderate current is at first passed through so as to heat it gradually. If one holds his hand near the coil, the invisible rays from the coil smite the skin, and set up there the sensation of heat. As the current is increased, the sensation of heat becomes more intense, and at length visible rays appear, and we have the sensation of light as well as heat.

Professor John Tyndall, of the Royal Institution, London, has written most interestingly about radiation in his book, entitled, "Heat a Mode of Motion."

Heating Buildings

The old-fashioned fireplace, with its large radiating surface, was a very effective means of heating a room. It depended not at all upon conduction nor convection, but wholly upon radiation. It was capable of radiating more heat than the largest steam radiator now in use, and it created a draught up the chimney which ventilated the room well. Of course it could not be supplied to many rooms in one house, and hence stoves were a very acceptable invention.

A stove heats a room both by radiation and convection. When we speak of heating a room, we are apt to think of the air in the room, although that is the poorest absorber

of heat, and probably has the least to do with warming us of anything in the room. When a stove is used, the air of the room is heated principally by convection, other objects, including ourselves, are heated principally by radiation. The stove is also a means of ventilating a room, since all the air which enters the stove to assist combustion passes on up the chimney.

We may picture to ourselves what happens about the stove as follows: —

1. Some of the air of the room pushes its way into the stove through the draught, and pushes the hotter, lighter air, together with the products of combustion, on up the chimney. In passing through the stove the air gives its oxygen to the fuel to support the combustion. This current of air from the room into the stove is a means of ventilating the room. The cause of its movement is that the fresh air from outside pushes into the room around doors and windows, because it is colder and heavier. Some of the air from the lungs of persons in the room is likely to be carried along in this current up chimney. Perfect ventilation would require that each person should discharge all his respired air out of doors directly, but such a scheme being impracticable, the best that we can do is to mingle as rapidly as possible pure air with the impure.

2. Some of the air of this room being in contact with the stove is heated, and expands. The cooler and heavier air of the room buoys this up away from the stove, and it goes directly to the top of the room in a straight stream. There it spreads out in a layer, in the same way that the alcohol behaves in water, as represented in Fig. 53. The cooler air having pushed its way to the stove is in turn heated and buoyed up to the top of the room. These topmost layers, as they cool, gradually settle until they again

reach the stove. Thus the air of a room is heated, and one who climbs to the top of the room is impressed with the wide difference in temperature between the upper and lower air of the same room when heated by artificial means. The air about the feet is cold and that about the head is hot. This is the reverse of that which might be desired, but is a physical necessity. The difference in temperature between the top and bottom of a room is often found to be as much as 6°.

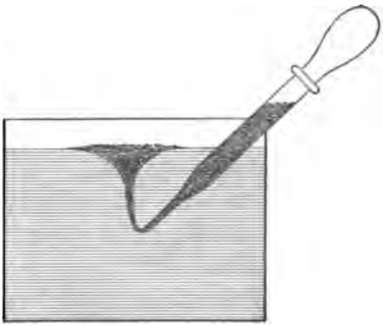

FIG. 53

There are, at least, three influences which tend to equalize these temperatures: (*a*) Gases of different density tend to diffuse into each other. This, however, is not sufficiently rapid between the warm and cold air of a room to cause much mixing. (*b*) The opening and closing of doors and moving about of persons stirs the air of a room. (*c*) Every object in the room is radiating heat in all directions. The air, however, is less affected by these rays than most objects.

3. The stove is a center from which shoot, in all directions, rays that increase molecular motion in the substances which they strike. Every object in the room is a center of radiation, but the stove is the more important source of radiation by as much as it is hotter than other things. These rays become more numerous and more effective as the stove grows hotter, and if the stove gets red-hot, light rays are mingled with the invisible ones. These rays affect different materials in different ways. If the stove stands near to woodwork, some of which is covered with

zinc and some of which has no zinc, but a covering of paint, the zinc will reflect the rays and protect the wood; but the paint, whatever its color may be, will absorb the rays and create heat in the wood. If the rays are intense enough, they may produce chemical change in the wood, leaving it charred. The air is transparent to the rays and is little affected by them, but most of the objects in the room absorb the rays and are heated by them. These objects may radiate heat long after the fire in the stove has gone out, and by their radiation they may keep the room comfortably warm after its air has been displaced by the cold outdoor air.

It is a great convenience to consolidate all the stoves of a house into one big stove and place it in the cellar near the coal bin, where it may be cared for by one person and its dirt may be kept out of the house. Such a device is called a furnace. It is really nothing but a large stove with an air-tight jacket around it. Figure 54 represents the essential features of the hot-air furnace. It is a vertical section through a cellar. *f* is the fire box, *a* the ash pit, *b* the door where the fuel is admitted, and *d* the door where the ashes are taken out. The fire box communicates with the chimney *c* by a smoke pipe *e*. So much constitutes the stove. Around this is the air space *g* made by putting a sheet-iron covering over the furnace and fitting it around the smoke pipe and the doors of the furnace in such a way that no smoke nor gases from the fire nor air from the cellar can get into the air chamber of the furnace. Fresh air from out doors enters this air space through the duct *h*, which is generally called the "cold-air box." This air when heated is pushed on through various pipes *p* and enters the rooms above through registers *r* placed either in the floors or walls. *k* is a slide with

which one may close more or less the cold-air duct as the weather may require. If the fire is low and the weather is cold and windy, it may be necessary to have the slide nearly closed to prevent cold air from passing into the rooms through the registers, but when the furnace fire is very hot it may be able to heat all the air that would pass if the slide were wide open. It sometimes happens that people try to heat their houses with the slide entirely closed. This is like trying to draw water from a faucet

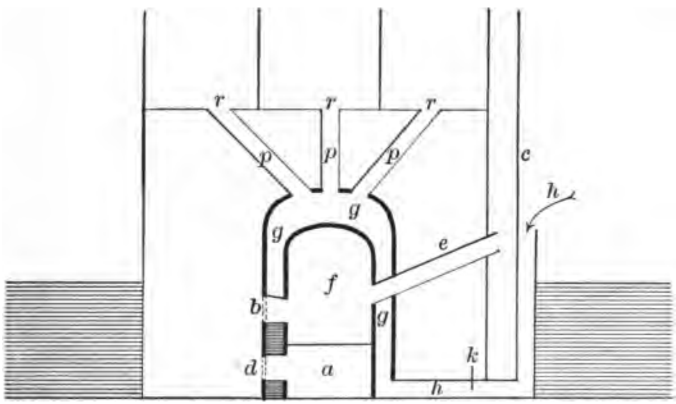

FIG. 54

with a stopcock back in the pipe closed. It very often happens that persons keep the slide more nearly closed than they should, and thus have to urge on the furnace unnecessarily and superheat the air which passes in order to warm the house sufficiently. The most desirable adjustment is that which will warm the air not above 70° and pass it in sufficient volume to make the house comfortable.

When the warm air enters a room, it goes directly to the top and spreads out underneath the ceiling. If any

windows are open at the top, it escapes forthwith out of doors. If no other exits are provided, the pressure of the outside air crowding into the room by way of the furnace slowly causes the air of the room to leak away through small openings around doors and windows. Meanwhile it has parted with some of its heat to the persons and things in the rooms of the house. Since the air is a poor conveyer of heat, we require a large amount of it to pass through the room to warm it on cold days, and this provides a very good means of ventilation. The air in passing over the furnace gets very dry, and in passing through the rooms carries away with it large volumes of moisture which evaporates from persons and things. This causes woodwork and furniture to check and fall to pieces, it causes the death of plants kept in the rooms, and is considered to be an aggravation of throat troubles and the cause of many ills to persons. The small waterpot which generally is inserted in the air chamber of the furnace, holding a gallon or two of water, is an attempt to relieve this condition, but a barrel of water a day would not be sufficient to supply the want in most cases, and scarcely a gallon a day evaporates from the waterpot.

A hot-water heating system is partially represented in Fig. 46, p. 67, but further details are given in Fig. 55. In a very general way we may think of the hot-water furnace as being like the hot-air furnace with a water jacket substituted for the air jacket. The water, however, after it has parted with some of its heat in the rooms above, is returned to the furnace to be heated again. *s* is the hot-water supply pipe, which sends branches to each of the radiators *r* placed in the various rooms of the house. These radiators are well named, since they should be thought of as sources of countless rays shooting out in all

directions to heat every object in the room. The radiator has a form which gives as much surface as possible for radiation and also for contact with the air of the room, so that it may cause convection currents also. When the water becomes cooler and heavier it presses down the return pipe *t* to the lower part of the furnace. The expansion and contraction of the water in the whole system, due to changes of temperature which may be as much as a cubic foot in a moderate-sized plant, is provided for by the expansion tank placed in any convenient part of the house. It must, however, be at the highest point of the system and must be open to the air. It is liable to emit steam if the furnace fire rages much. The water, however, will not ordinarily be heated above 150° in the coldest weather. In Fig. 55, *v* represents the expansion tank.

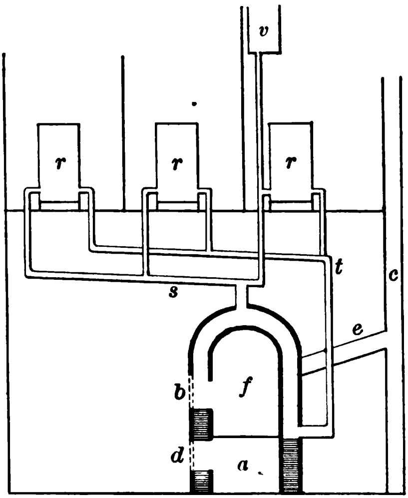

Fig. 55

Figure 55, if the expansion tank be omitted, may also be used to represent the essentials of a steam-heating system. In this case the water at the furnace is boiled and the pipes and radiators are filled with steam only. A cubic foot of water will make about 1700 cubic feet of steam, and hence expansion and contraction are very great in this system. The system is therefore provided with a

safety valve which may be adjusted so as to let out steam when its pressure rises above any given point.

Water boils at 212° only when freely open to the atmosphere. If the pressure upon it is increased, its boiling temperature will increase in a fixed ratio. Since the fireman has a pressure gauge, but no thermometer, on his boiler, he speaks of pressure when he wishes to refer to temperature. The steam pressure is rarely allowed to run as high as 10 pounds per square inch. Even in cold weather 5 pounds pressure is sufficient if the radiators are as large as they should be. When the steam pressure is 5 pounds its temperature is 228°, and when it is 10 pounds the temperature is 240°.

Whenever the valves of a radiator are closed the steam in it condenses to a very small amount of water, and air is pretty sure to get in somehow and fill the radiator. It is necessary to get this air out before steam can pass in again. Figure 56 represents a device for accomplishing this. *R* is the body of the radiator, only a small portion of which is represented. *a* is the pet valve as it is called. The arrows show the air passing out of the radiator. When, however, steam begins to pass, it heats the metal plug *a*, which expands and closes the opening. This remains closed as long as the radiator is hot, but it contracts and opens the outlet again whenever the radiator is cold. This plug has a slot cut in the end to receive a screwdriver, and has threads cut along its sides so that its distance from the opening in the radiator may be adjusted. When properly controlled

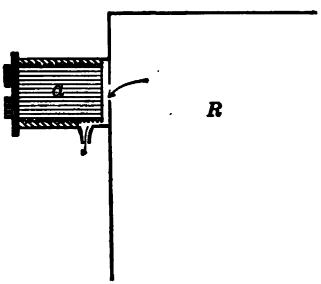

FIG. 56

these pet valves are a great convenience, but when neglected they become a nuisance. For if the plug is screwed in a little too far, the air cannot get out, and steam cannot pass into the radiator when the steam valves are opened. They are then said to be air-locked. On the other hand, if the plug is unscrewed a little too far, it fails to close when hot, and steam continues to flow out into the room, sometimes mingled with water which has lodged in the radiator, and this does damage to plaster, woodwork, and furniture. The pet valve may be controlled so as to let a small amount of steam out into the room without damage, and thus relieve the dryness of the air.

Ventilation of Buildings

Only in very recent years has any attention been paid to ventilation, but it is rapidly coming to be considered of the utmost importance. The lack of fresh air is known to be the cause of many ills, and in some states the health of the school children is protected by a law requiring that every school building shall be equipped with ventilating apparatus which is capable of supplying 30 cubic feet of fresh air per minute to each pupil.

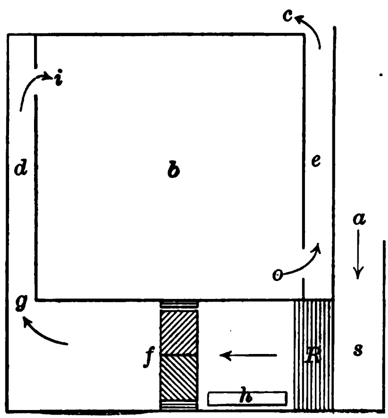

Fig. 57

Figure 57 shows the essential features of a type of heating and ventilating plant much used for school buildings. *b* is a schoolroom shown in vertical section, *a* is the fresh-air inlet for the

whole building. Every effort is made to procure the purest air available for the given building. To avoid dust, leaves, waste-paper, smoke, etc., which blow about in the atmosphere of a city, this inlet is usually placed in an inclosed court in the rear of the building, and a wire netting is placed over the mouth of the inlet to strain out the larger objects which float in the air, and sometimes screens of cheese cloth are also used to filter the smoke and dust from the air. The air then passes over a stack of steam pipes *R* to warm it. This inevitably makes it too dry for health and comfort, and sometimes, therefore, a device *h* is used for increasing the humidity of the air. This is simply a shallow tank kept full of water by a ball-cock (see p. 66), and having steam pipes coiled about in the water to cause it to evaporate rapidly. The warm air charged with the proper amount of moisture is now carried through the fan *f*, which is the cause of the movement of the air. The fan is driven by a steam engine, an electric motor, or sometimes a water motor. The air is then driven up the duct *d* and out into the top of the room through the inlet register *i*. There are several reasons why the inlet register is placed at the top of the room. (1) If there are fifty pupils in the room, the inlet register must admit 1500 cubic feet of air per minute. This would be a disagreeable and dangerous draught for the pupils sitting near it if the register were near the bottom of the room. (2) If the warmer air were brought in at the bottom of the room it would go to the top quite directly, but foul air would mingle with it in passing.

The warm pure air crowded in at the top of the room pushes the rest of the air of the room out through the outlet register *o* and up the outlet duct *e* to the top of the building. If the outlet register were at the top of the

room, the warm air would go directly from the inlet to the outlet registers without helping much the occupants of the room. Sometimes other fans are placed in the garret to assist the moving of the air out into the atmosphere. It will require about 60 horse power to move sufficient air for a thousand pupils, and it is rather a complex question how the fans should be distributed. If they are all placed in the basement, the arrangement will have this advantage that the air being moved by pressure from behind will exert an outward push at the cracks about windows and doors, and thus relieve the occupants from disagreeable indraughts of cold air.

The steam pipes *R* are called the primary coils. They are so regulated by thermostats as to give the air the proper temperature. Since, however, some rooms are more exposed or are more remote from this heating stack than others, secondary coils *g* are placed in some or most of the ducts which lead to individual rooms, so that the air may be delivered to the room at the right temperature — 68°. Each room has its thermostat (see p. 81), which controls the secondary coils for that room, and some typical room has an humidostat which controls the humidifier *h*. The essential thing about the humidostat is a thin strip of wood with another thin shaving of wood glued to it, having its grain at right angles to the first.

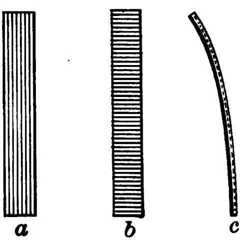

FIG. 58

Figure 58, *a*, shows the face of this compound strip of wood which has the grain running lengthwise, *b* shows the other side of the strip having the grain crosswise, and *c* shows the edge of the strip as it behaves when moist. Wood swells crosswise but not lengthwise the

grain when moist. This compound wooden strip is made to turn on and off steam in the shallow tank *h*, Fig. 57, in precisely the same way that the compound metal strip in the thermostat turns on and off steam in the secondary coils (see p. 81).

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Woodhull, J.F. 621377
Elementary physical science.

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